

A DIRECT PROOF OF THE FIVE ELEMENT BASIS THEOREM

BOBAN VELIČKOVIĆ AND GIORGIO VENTURI

ABSTRACT. We present a direct proof of the consistency of the existence of a five element basis for the uncountable linear orders. Our argument is based on the approach of Larson, Koenig, Moore and Velickovic and simplifies the original proof of Moore.

INTRODUCTION

In [11] Moore showed that PFA implies that the class of the uncountable linear orders has a five element basis, i.e., that there is a list of five uncountable linear orders such that every uncountable linear order contains an isomorphic copy of one of them. This basis consists of X , ω_1 , ω_1^* , C , and C^* , where X is any suborder of the reals of cardinality ω_1 and C is any Countryman line¹. It was previously known from the work of Baumgartner [5] and Abraham-Shelah [1], that, assuming a rather weak forcing axiom, the existence of a five element linear basis for uncountable linear orderings is equivalent to the following statement, called the *Coloring Axiom for Trees* (CAT):

There is a normal Aronszajn tree T such that for every $K \subseteq T$ there is an uncountable antichain $X \subseteq T$ such that $\wedge(X)$ is either contained in or disjoint from K .

Here, $\wedge(X)$ is the set of all pairwise meets of incomparable elements of X . One feature of the argument from [11] is that it relies crucially on the Mapping Reflection Principle (MRP), a strong combinatorial principle previously introduced by Moore in [12], in order to prove the properness of the appropriate forcing notion. It was shown in [12] that MRP implies the failure of \square_κ , for all $\kappa \geq \omega_1$, and therefore its consistency requires very large cardinal axioms. However, it was not clear if any large cardinals were

2000 Mathematics Subject Classification. Primary: 03E35, 03E75, 06A05; Secondary: 03E02.

Key words and phrases. Aronszajn trees, Countryman type, forcing axioms, BPFA, linear order, Shelah's conjecture.

¹Recall that a *Countryman line* is an uncountable linear order whose square is the union of countably many non-decreasing relations. The existence of such a linear order was proved by Shelah in [13].

needed for the relative consistency of CAT. Progress on this question was made by König, Larson, Moore and Veličković in [9] who reduced considerably the large cardinal assumptions in Moore's proof. They considered a statement φ which is a form of saturation of Aronszajn trees and showed that it can be used instead of MRP in the proof of the Key Lemma (Lemma 5.29) from [11]. Moreover, they showed that for the consistency of BPFA together with φ it is sufficient to assume the existence of a reflecting Mahlo cardinal. If one is only interested in the consistency of the existence of a five element basis for the uncountable linear orderings then even an smaller large cardinal assumption is sufficient (see [9] for details).

The purpose of this note is to present a direct proof of CAT, and therefore the existence of a five element linear basis, assuming the conjunction of BPFA and φ . The argument is much simpler than the original proof from [11]. It is our hope that by further understanding this forcing one will be able to determine if any large cardinal assumptions are needed for the consistency of CAT.

The paper is organized as follows. In §1 we present the background material on Aronszajn trees and the combinatorial principles ψ and φ . In §2 we start with a coherent special Aronszajn tree T and a subset K of T , define a new coloring of finite subsets of T and prove some technical lemmas. In §3 we define the main forcing notion $\partial^*(K)$ and show that it is proper. In §4 we complete the proof that BPFA together with φ implies CAT.

1. SATURATION OF ARONSZAJN TREES

Recall that a *tree* is a partially ordered $(T, <)$ such that for every $t \in T$ the set of predecessors of t , i.e. $\{s \in T : s < t\}$, is well ordered. If $t \in T$ we let $\text{ht}(t)$ denote the height of t in T , i.e. the order type of $\{s \in T : s < t\}$. If $t \in T$ and $\xi < \text{ht}(t)$ we let $t \upharpoonright \xi$ denote the unique predecessor of t of height ξ . For an ordinal α we let T_α denote the α -th level of T i.e. the set of all $t \in T$ of height α . T is called *normal* if it has a unique least element, i.e. the *root*, any two nodes of limit height that have the same predecessors are actually equal. If T is normal and $s, t \in T$ then there is the largest node, denoted by $s \wedge t$, below s and t . We also refer to $s \wedge t$ as the *meet* of s and t . The *height* of T , denoted by $\text{ht}(T)$, is the least α such that T_α is empty. A *chain* in T is a totally ordered subset C of T . An *antichain* in T is a subset A of T such that any two elements of A are pairwise incomparable. By an *Aronszajn tree* or simply an *A-tree* we mean a tree of height ω_1 in which all levels and chains are at most countable. A *subtree* of an A-tree T is an uncountable downwards closed subset of T . We start by discussing the notion of saturation of an Aronszajn tree.

Definition 1.1. *An Aronszajn tree T is saturated if, whenever \mathcal{A} is a collection of subtrees of T such that the intersection of any two trees in \mathcal{A} is at most countable, \mathcal{A} has cardinality at most ω_1 .*

It was shown by Baumgartner in [4] that the following holds after Levy collapsing an inaccessible cardinal to ω_2 with countable conditions.

For every Aronszajn tree T , there is a collection \mathcal{B} of subtrees of T such that \mathcal{B} has cardinality ω_1 and every subtree of T contains an element of \mathcal{B} .

Clearly, this statement implies that every A-tree is saturated. In order to obtain CAT we will use a form of saturation of A-tree together with BPFA. In Baumgartner's model CH holds hence it is not suitable for our purpose. It is for this reason that a different approach was taken in [9]. We now recall the relevant definitions from this paper.

If \mathcal{F} is a collection of subtrees of T , then \mathcal{F}^\perp is the collection of all subtrees B of T such that for every A in \mathcal{F} , $A \cap B$ is countable. If \mathcal{F}^\perp is empty, then \mathcal{F} is said to be *predense*. For \mathcal{F} a collection of subtrees of an Aronszajn tree T , we consider the following statements:

$\psi_0(\mathcal{F})$: There is a closed unbounded set $E \subseteq \omega_1$ and a continuous chain $(N_\nu : \nu \in E)$ of countable subsets of \mathcal{F} such that for every ν in E and t in T_ν there is a $\nu_t < \nu$ such that if $\xi \in (\nu_t, \nu) \cap E$, then there is $A \in N_\xi$ such that $t \restriction \xi$ is in A .

$\varphi_0(\mathcal{F})$: There is a closed unbounded set $E \subseteq \omega_1$ and a continuous chain $(N_\nu : \nu \in E)$ of countable subsets of $\mathcal{F} \cup \mathcal{F}^\perp$ such that for every ν in E and t in T_ν either

- (1) there is a $\nu_t < \nu$ such that if $\xi \in (\nu_t, \nu) \cap E$, then there is $A \in \mathcal{F} \cap N_\xi$ such that $t \restriction \xi$ is in A , or
- (2) there is a B in $\mathcal{F}^\perp \cap N_\nu$ such that t is in B .

It is not difficult to show that $\psi_0(\mathcal{F})$ implies that \mathcal{F} is predense, indeed that $\bigcup_\nu N_\nu$ is predense. Hence, if $\psi_0(\mathcal{F})$ holds for every predense family of subtrees of T , then T is saturated. It is also clear that $\psi_0(\mathcal{F})$ is a Σ_1 -formula with parameters \mathcal{F} and T . While $\varphi_0(\mathcal{F})$ and $\psi_0(\mathcal{F})$ are equivalent if \mathcal{F} is predense, $\varphi_0(\mathcal{F})$ is in general not a Σ_1 -formula in \mathcal{F} and T . Let φ be the assertion that if T is an Aronszajn tree and \mathcal{F} is a family of subtrees T then $\varphi_0(\mathcal{F})$ holds, and let ψ be the analogous assertion but with quantification only over \mathcal{F} that are predense. As noted, φ implies ψ . The following was proved as Corollary 3.9 in [9].

Proposition 1.2. *For a given family \mathcal{F} of subtrees of an Aronszajn tree T , there is a proper forcing extension which satisfies $\varphi_0(\mathcal{F})$. \square*

Remark 1.3. If we want to force φ it is natural to start with an inaccessible cardinal κ and do a countable support iteration of proper forcing notions

$(\mathcal{P}_\alpha, \dot{Q}_\beta; \alpha \leq \kappa, \beta < \kappa)$. At stage α we can use \diamond_κ to guess an Aronszajn tree \dot{T}_α and a family $\dot{\mathcal{F}}_\alpha$ of subtrees of \dot{T}_α in the model $V^{\mathcal{P}_\alpha}$ and let \dot{Q}_α be a \mathcal{P}_α -name for the proper poset which forces $\varphi_0(\dot{\mathcal{F}}_\alpha)$. Suppose in the final model $V^{\mathcal{P}_\kappa}$ we have an Aronszajn tree \dot{T} and a family $\dot{\mathcal{F}} \in V^{\mathcal{P}_\kappa}$ of subtrees of \dot{T} . In order to ensure that $\varphi_0(\dot{\mathcal{F}})$ holds in $V^{\mathcal{P}_\kappa}$ we need to find a stage α of the iteration at which \dot{T} and $\dot{\mathcal{F}}$ are guessed, i.e. $\dot{T}_\alpha = \dot{T}$ and $\dot{\mathcal{F}} \upharpoonright V^{\mathcal{P}_\alpha} = \dot{\mathcal{F}}_\alpha$ and moreover such that

$$(\dot{\mathcal{F}}^\perp)^{V^{\mathcal{P}_\kappa}} \upharpoonright V^{\mathcal{P}_\alpha} = (\dot{\mathcal{F}}_\alpha^\perp)^{V^{\mathcal{P}_\alpha}}.$$

This is the reason why a Mahlo cardinal is used in the following theorem from [9].

Theorem 1.4. *If there is a cardinal which is both reflecting and Mahlo, then there is a proper forcing extension of L which satisfies the conjunction of BPFA and φ . In particular the forcing extension satisfies that the uncountable linear orders have a five element basis.* \square

If one is interested only in the consistency of the existence of a five element basis for the uncountable linear orderings it was observed in [9] then a somewhat smaller large cardinal is sufficient. Indeed, for the desired conclusion one does not need the full strength of BPFA and one only needs $\varphi_0(\mathcal{F})$ for certain families of subtrees of an Aronszajn tree T which are Σ_1 -definable using a subset of ω_1 as a parameter. The precise large cardinal assumption is that there is an inaccessible cardinal κ such that for every $\kappa_0 < \kappa$, there is an inaccessible cardinal $\delta < \kappa$ such that κ_0 is in $H(\delta)$ and $H(\delta)$ satisfies there are two reflecting cardinals greater than κ_0 .

2. COLORINGS OF ARONSZAJN TREES

Let $2^{<\omega_1}$ denote the full binary tree of height ω_1 with the usual ordering. For the remainder of the paper we fix an Aronszajn tree $T \subseteq 2^{<\omega_1}$ which is special, coherent, and closed under finite modifications. The tree $T(\varrho_3)$ from [17] is such an example. Recall that T is *special* if it can be written as $T = \bigcup_n A_n$, where A_n is an antichain, for all n . Notice that this implies that any uncountable subset of T contains an uncountable antichain. We will often use this fact without mentioning it. Since T is a subtree of $2^{<\omega_1}$, the α -th level of T , i.e. T_α , is simply $T \cap 2^\alpha$. We say that T is *coherent* if, for every countable α and $s, t \in T_\alpha$, the set

$$D(s, t) = \{\xi < \alpha : s(\xi) \neq t(\xi)\}$$

is finite. Finally, T is *closed under finite modifications* if, for every α and $s, t \in 2^\alpha$, if $s \in T$ and $D(s, t)$ is finite then $t \in T$. For $A \subseteq \omega_1$ we set

$T \upharpoonright A = \bigcup_{\alpha \in A} T_\alpha$. If s and t are incomparable nodes in T , i.e. if $D(s, t)$ is non-empty, we let

$$\Delta(s, t) = \min D(s, t).$$

Since T is a subtree of $2^{<\omega_1}$ which is normal it is itself normal. If $s, t \in T$ then the meet of s and t , i.e. $s \wedge t$, is simply $s \upharpoonright \Delta(s, t)$. Given a subset X of T we let

$$\wedge(X) = \{s \wedge t : s, t \in X, s \text{ and } t \text{ incomparable}\}.$$

Note that if T_X is the tree induced by X , i.e. the set of all initial segments of elements of X , then $\wedge(T_X) = \wedge(X)$. We also let

$$\pi(X) = \{t \upharpoonright \text{ht}(s) : s, t \in X \text{ and } \text{ht}(s) \leq \text{ht}(t)\}.$$

We let $\text{lev}(X) = \{\text{ht}(t) : t \in X\}$. If $\alpha \in \text{lev}(X)$ we let $\pi_\alpha(X) = \pi(X) \cap T_\alpha$.

We will also need to consider finite powers of our tree T . Given an integer n and a level T_α of T we let

$$T_\alpha^{[n]} = \{\tau \in T_\alpha^n : i < j \rightarrow \tau(i) \leq_{\text{lex}} \tau(j)\}$$

where \leq_{lex} denotes the lexicographic ordering of T . We let $T^{[n]} = \bigcup_\alpha T_\alpha^{[n]}$. Morally, elements of $T^{[n]}$ are n -element subsets of T of the same height. In order to ensure that $T^{[n]}$ is closed under taking restrictions, it is necessary to allow for n -element sets with repetitions, i.e. *multisets*, and the above definition is a formal way to accommodate this. We will abuse notation and identify elements of $T^{[n]}$ that have distinct coordinates with the set of their coordinates. In our arguments, only the range of these sequences will be relevant.

If $\sigma \in T_\alpha^{[n]}$ and $\tau \in T_\alpha^{[m]}$, for some α , then, by abusing notation, we will write $\sigma \cup \tau$ is the sequence of length $n + m$ which enumerates the coordinates of σ and τ in \leq_{lex} -increasing order including repetitions. We will also write $\sigma \subseteq \tau$ if the multiset enumerated by σ is included in the multiset enumerated by τ by counting multiplicities. $T^{[n]}$ will be considered as a tree with the coordinate-wise partial order induced by T . If $\sigma \in T^{[n]}$ and $\alpha < \text{ht}(\sigma)$ we write $\sigma \upharpoonright \alpha$ for the sequence $(\sigma(i) \upharpoonright \alpha : i < n)$. If $\sigma, \tau \in T^{[n]}$ are incomparable we will let

$$\Delta(\sigma, \tau) = \min\{\alpha : \sigma(i)(\alpha) \neq \tau(i)(\alpha), \text{ for some } i < n\}$$

and we will write $\sigma \wedge \tau$ for $\sigma \upharpoonright \Delta(\sigma, \tau)$.

For $\sigma \in T^{[n]}$ let

$$D_\sigma = (D(\sigma(i), \sigma(0)) : i < n)$$

Suppose $\sigma, \tau \in T^{[n]}$ and $\text{ht}(\sigma) \leq \text{ht}(\tau)$. We say that the pair $\{\sigma, \tau\}$ is *regular* if $D_\tau \upharpoonright \text{ht}(\sigma) = D_\sigma$, i.e. for all $i < n$,

$$D(\tau(i), \tau(0)) \cap \text{ht}(\sigma) = D(\sigma(i), \sigma(0)).$$

Note that in this case, for all $i, j < n$,

$$\Delta(\tau(i), \sigma(i)) = \Delta(\tau(j), \sigma(j)).$$

We say that a subset X of $T^{[n]}$ is *regular* if every pair of elements of X is regular. Note that if X is regular, then so is the tree T_X generated by X . A *level sequence* of $T^{[n]}$ is a sequence $\{\sigma_\alpha : \alpha \in A\}$ where A is a subset of ω_1 and $\sigma_\alpha \in T_\alpha^{[n]}$, for all $\alpha \in A$. The following is a simple application of the Δ -system lemma and the Pressing Down Lemma.

Fact 2.1. *Let $\mathcal{A} = \{\sigma_\alpha : \alpha \in A\}$ be a level sequence. If A is uncountable (stationary) then there is an uncountable (stationary) subset B of A such that $\mathcal{B} = \{\sigma_\alpha : \alpha \in B\}$ is regular. \square*

From now on we assume the conjunction of BPFA and φ . We are given a subset K of T and we want to find an uncountable antichain X in T such that $\wedge(X) \subseteq K$ or $\wedge(X) \cap K = \emptyset$. We will refer to K as a *coloring* of T . We first note that, for every integer n , K induces a coloring $K^{[n]}$ of $T^{[n]}$ defined by

$$K^{[n]} = K^n \cap T^{[n]}.$$

We let \mathcal{F}_n be the collection of regular subtrees R of $T^{[n]}$ such that $\wedge(R) \cap K^{[n]} = \emptyset$. The following fact is immediate by using Fact 2.1.

Fact 2.2. *If $R \in \mathcal{F}_n^\perp$ then for every uncountable $X \subseteq R$ there are incomparable $\sigma, \tau \in X$ such that $\sigma \wedge \tau \in K^{[n]}$.*

Proof. We may assume that X is a level sequence, say $X = \{\sigma_\alpha : \alpha \in A\}$, for some $A \subseteq \omega_1$. Since $T^{[n]}$ is special, by shirking X if necessary, we may assume that it is an antichain. By Fact 2.1 we may further assume that X is regular. Now, if $\wedge(X)$ were disjoint from $K^{[n]}$, then so would be $\wedge(T_X)$. But then T_X would belong to \mathcal{F}_n . However, T_X is a subtree of R which is orthogonal to all trees in \mathcal{F}_n , a contradiction. \square

By $\varphi_0(\mathcal{F}_n)$ we can find a club C_n in ω_1 and a continuous increasing chain $(N_\xi^n : \xi \in C_n)$ of countable subsets of $\mathcal{F}_n \cup (\mathcal{F}_n)^\perp$ witnessing $\varphi_0(\mathcal{F}_n)$. By replacing each of the C_n by their intersection we may assume that the C_n are all the same and equal to say C . We now define a new coloring of $T^{[n]} \upharpoonright C$ as follows.

Definition 2.3. *A node $\sigma \in T^{[n]} \upharpoonright C$ is in $K_\varphi^{[n]}$ if, letting α be the height of σ , there exists $R \in (\mathcal{F}_n)^\perp \cap N_\alpha^n$ such that $\sigma \in R$, i.e. if σ is in case (2) of the dichotomy for $\varphi_0(\mathcal{F}_n)$. We denote $(T^{[n]} \upharpoonright C) \setminus K_\varphi^{[n]}$ by $L_\varphi^{[n]}$. We let $K_\varphi = \bigcup_n K_\varphi^{[n]}$ and $L_\varphi = \bigcup_n L_\varphi^{[n]}$.*

Remark 2.4. The induced coloring $T^{[n]} = K_\varphi^{[n]} \cup L_\varphi^{[n]}$, for $n < \omega$, is our analog of the notions of *acceptance* and *rejection* from [11]. The main difference is that these notions are defined in [11] relative to a given countable elementary submodel of $H(\omega_2)$ whereas our colorings do not make reference to any such model. This simplifies considerably the proof of properness of the main forcing notion we define in §3.

We now note some useful facts about these induced colorings.

Fact 2.5. *If there is a node t in $L_\varphi^{[1]}$ whose height is a limit point of C then there is an uncountable antichain X in T such that $\wedge(X) \cap K = \emptyset$.*

Proof. Assume t is such a node and let α be the height of t . By our assumption, case (1) of the dichotomy for $\varphi_0(\mathcal{F}_1)$ holds for t . Therefore, there exists $\eta < \alpha$ such that for every $\xi \in (\eta, \alpha) \cap C$ there is a $R \in \mathcal{F}_1 \cap N_\xi^1$ such that $t \restriction \xi \in R$. Since $(\eta, \alpha) \cap C$ is non-empty, it follows that \mathcal{F}_1 is non-empty, as well. Now, let R be a member of \mathcal{F}_1 . Identifying R with a subtree of T we have that $\wedge(R) \cap K = \emptyset$. Since T is special, so is R and we can fix an uncountable antichain X in R . It follows that $\wedge(X) \cap K = \emptyset$, as required. \square

Fact 2.6. *If $\sigma \in K_\varphi$ and $\alpha = \text{ht}(\sigma)$ is a limit point of C then there is $\eta < \alpha$ such that $\sigma \restriction \xi \in K_\varphi$, for all $\xi \in (\eta, \alpha) \cap C$. Similarly for L_φ . We refer to this property as continuity of the induced coloring.* \square

Fact 2.7. *Suppose S is a stationary subset of C and $\mathcal{S} = \{\sigma_\xi : \xi \in S\}$ is a level sequence in $T^{[n]}$ consisting of elements of $K_\varphi^{[n]}$. Then there exist distinct $\xi, \eta \in S$ such that $\sigma_\xi \wedge \sigma_\eta \in K^{[n]}$.*

Proof. For $\xi \in S$ since $\sigma_\xi \in K_\varphi^{[n]}$ there exists a tree $R_\xi \in N_\xi^n \cap (\mathcal{F}_n)^\perp$ such that $\sigma_\xi \in R_\xi$. Since $(N_\xi^n : \xi \in C)$ is a continuous increasing sequence of countable sets, we can apply the Pressing Down Lemma to the function $\xi \mapsto R_\xi$. Hence, by shrinking S if necessary, we may assume that the trees R_ξ are all the same and equal to some R . This simply means that $\mathcal{S} \subseteq R$. Since $R \in (\mathcal{F}_n)^\perp$, by Fact 2.2, there are $\xi \neq \eta \in S$ such that $\sigma_\eta \wedge \sigma_\xi \in K^{[n]}$, as required. \square

Definition 2.8. *Let $\mathcal{S} = \{\sigma_\xi : \xi \in A\}$ be a regular level sequence in $T^{[n]}$, for some integer n . Then $\mathcal{P}_\mathcal{S}$ is the poset consisting of finite subsets p of \mathcal{S} such that $\wedge(p) \cap K^{[n]} = \emptyset$, ordered by reverse inclusion.*

The following lemma is the main technical result of this section.

Lemma 2.9. *Let $\mathcal{S} = \{\sigma_\alpha : \alpha \in S\}$ and $\mathcal{Z} = \{\tau_\gamma : \gamma \in Z\}$ be two regular level sequences in $T^{[n]}$ and $T^{[m]}$ respectively such that S is a stationary*

subset of C and $S \subseteq K_\varphi^{[n]}$. Assume that, for every $\alpha \in S$ and $\gamma \in Z$, if $\alpha < \gamma$ then

$$\sigma_\alpha \cup \tau_\gamma \upharpoonright \alpha \in L_\varphi^{[n+m]}.$$

Then \mathcal{P}_Z is c.c.c.

Proof. Before starting the proof, notice that by using the Pressing Down Lemma and shrinking S if necessary we may assume that there is a fixed tree $R_0 \in (\mathcal{F}_n)^\perp$ witnessing that σ_α is in $K_\varphi^{[n]}$, for all $\alpha \in S$. By shrinking S and Z if necessary we may moreover assume that for every $\alpha \in S$, $\gamma \in Z$, every $i < n$ and $j < m$, $\sigma_\alpha(i)$ and $\tau_\gamma(j)$ are incomparable in T .

Now, assume \mathcal{A} is an uncountable subset of \mathcal{P}_Z . We need to find distinct p and q in \mathcal{A} which are compatible, i.e. such that $\wedge(p \cup q) \cap K^{[m]} = \emptyset$. By a standard Δ -system argument we can assume that all elements of \mathcal{A} have a fixed size k and are mutually disjoint. For each $\alpha \in S$ we pick an element p_α of \mathcal{A} such that $\text{ht}(\tau) > \alpha$, for all $\tau \in p_\alpha$.

Fix for a moment one such α . Since by our assumption $\sigma_\alpha \cup \tau \upharpoonright \alpha \in L_\varphi^{[n+m]}$, for all $\tau \in p_\alpha$, we can fix an ordinal $\eta_\alpha < \alpha$ such that for every $\xi \in (\eta_\alpha, \alpha) \cap C$ and every $\tau \in p_\alpha$ there is a tree $R \in \mathcal{F}_{n+m} \cap N_\xi^{n+m}$ such that $\sigma_\alpha \upharpoonright \xi \cup \tau \upharpoonright \xi \in R$. By applying the Pressing Down Lemma and shrinking S again we may assume that all the ordinals η_α are equal to some η^* .

Now, for each $\alpha \in S$, fix an enumeration $\{v_\alpha^0, \dots, v_\alpha^{l_\alpha-1}\}$ of distinct elements of $\{\tau \upharpoonright \alpha : \tau \in p_\alpha\}$. We may assume that there is a fixed integer l such that $l_\alpha = l$, for all $\alpha \in S$. Moreover, by shrinking S further, we may assume that if $\alpha, \beta \in S$ are distinct then v_α^i and v_β^j are incomparable, for all $i, j < l$. For each $\alpha \in S$ let

$$F_\alpha = \{\sigma_\alpha(j) : j < n\} \cup \{v_\alpha^i(j) : i < l, j < m\}$$

and let

$$D_\alpha = \bigcup \{D(s, t) : s, t \in F_\alpha\}.$$

Then D_α is finite, so if α is a limit ordinal and we let $\xi_\alpha = \max(D_\alpha) + 1$ then $\xi_\alpha < \alpha$. By the Pressing Down Lemma and shrinking S yet again we may assume that there exists a fixed ordinal ξ , a sequence $\sigma \in T_\xi^{[n]}$, and sequences $v^i \in T_\xi^{[m]}$, for $i < l$, such that, for each $\alpha \in S$, we have:

- (1) $\xi_\alpha = \xi$,
- (2) $\sigma_\alpha \upharpoonright \xi = \sigma$,
- (3) $v_\alpha^i \upharpoonright \xi = v^i$, for $i < l$.

Now, notice that if $\alpha, \beta \in S$ are distinct, then for every $i < l$,

$$\Delta(v_\alpha^i, v_\beta^i) = \Delta(\sigma_\alpha, \sigma_\beta).$$

Moreover, if i and j are distinct then

$$v_\alpha^i \wedge v_\beta^j = v_\alpha^i \wedge v_\alpha^j = v_\beta^i \wedge v_\beta^j \notin K^{[m]}.$$

Therefore, p_α and p_β are compatible in \mathcal{P}_Z provided $v_\alpha^i \wedge v_\beta^i \notin K^{[m]}$, for all $i < l$. We have finally set the stage for the proof of the lemma.

Fix a sufficiently large regular cardinal θ and a countable elementary submodel M of $H(\theta)$ containing all the relevant objects and such that $\delta = M \cap \omega_1$ belongs to S . Working in M fix a countable elementary submodel N of $H(\omega_2)$ containing all the relevant objects and let $\zeta = N \cap \omega_1$. Now, by our assumption $\eta^*, C \in N$, C is a club, and $N \in M$, and so we have that $\zeta \in (\eta^*, \delta) \cap C$. Therefore, for each $i < l$ there exists a tree $A_i \in \mathcal{F}_{n+m} \cap N_\zeta^{n+m}$ such that $\sigma_\delta \upharpoonright \zeta \cup v_\delta^i \upharpoonright \zeta \in A_i$. Since $N_\zeta^{n+m} \subseteq N$ we know that $A_i \in N$, for all i . Let

$$H = \{\eta : \exists \alpha \in S[\alpha > \eta \wedge \forall i < l(\sigma_\alpha \upharpoonright \eta \cup v_\alpha^i \upharpoonright \eta \in A_i)]\}$$

Since all the parameters in the definition of H are in N , by elementarity of N it follows that $H \in N$. On the other hand $\zeta \in H \setminus N$, therefore H is uncountable. Fix a 1 – 1 function $f : H \rightarrow S$ with $f \in N$ such that for every $\eta \in H$, $f(\eta)$ witnesses that $\eta \in H$. Then the set $X = \{\sigma_{f(\eta)} : \eta \in H\}$ belongs to N . We also know that X is an uncountable subset of R_0 . Since $T^{[n]}$ is a special tree, by shrinking H we may assume that $Y = \{\sigma_{f(\eta)} \upharpoonright \eta : \eta \in H\}$ is an antichain in $T^{[n]}$. Since $Y \subseteq R_0$ and $R_0 \in (\mathcal{F}_n)^\perp$, by Fact 2.2, there are distinct $\eta, \rho \in H$ such that:

$$\sigma_{f(\eta)} \wedge \sigma_{f(\rho)} = \sigma_{f(\eta)} \upharpoonright \eta \wedge \sigma_{f(\rho)} \upharpoonright \rho \in K^{[n]}.$$

Let $\alpha = f(\eta)$ and $\beta = f(\rho)$. We claim that p_α and p_β are compatible in \mathcal{P}_Z . To see this, consider some $i < l$. We know that $\sigma_\alpha \upharpoonright \eta \cup v_\alpha^i \upharpoonright \eta$ and $\sigma_\beta \upharpoonright \rho \cup v_\beta^i \upharpoonright \rho$ belong to A_i . Therefore,

$$(\sigma_\alpha \cup v_\alpha^i) \wedge (\sigma_\beta \cup v_\beta^i) = (\sigma_\alpha \upharpoonright \eta \cup v_\alpha^i \upharpoonright \eta) \wedge (\sigma_\beta \upharpoonright \rho \cup v_\beta^i \upharpoonright \rho) \notin K^{[n+m]}.$$

Since $\sigma_\alpha \wedge \sigma_\beta \in K^{[n]}$ it follows that

$$v_\alpha^i \wedge v_\beta^i \notin K^{[m]}.$$

Since this is true for all i it follows that p_α and p_β are compatible. \square

Lemma 2.10 (MA_{\aleph_1}). *Let $\mathcal{S} = \{\sigma_\alpha : \alpha \in S\}$ and $\mathcal{Z} = \{\tau_\gamma : \gamma \in Z\}$ be two regular level sequences in $T^{[n]}$ and $T^{[m]}$ respectively such that S and Z are stationary subsets of C . Assume $\mathcal{S} \subseteq K_\varphi^{[n]}$ and $\mathcal{Z} \subseteq K_\varphi^{[m]}$. Then there exist $\alpha \in S$ and $\gamma \in Z$ such that $\alpha < \gamma$ and*

$$\sigma_\alpha \cup \tau_\gamma \upharpoonright \alpha \in K_\varphi^{[n+m]}.$$

Proof. For every $\gamma \in Z$ fix a tree $R_\gamma \in (\mathcal{F}_m)^\perp \cap N_\gamma^m$ such that $\tau_\gamma \in R_\gamma$, i.e. witnessing that $\tau_\gamma \in K_\varphi^{[m]}$. Since Z is stationary by the Pressing Down Lemma and shrinking Z if necessary we may assume that all the R_γ are equal to some tree R . Assume towards contradiction that for every $\alpha \in S$ and $\gamma \in Z$, if $\alpha < \gamma$ then $\sigma_\alpha \cup \tau_\gamma \upharpoonright \alpha \in L_\varphi^{[n+m]}$. By Lemma 2.9 \mathcal{P}_Z is c.c.c. By MA_{\aleph_1} we can find an uncountable subset Y of Z such that $\tau_\alpha \wedge \tau_\beta \notin K^{[m]}$, for every distinct $\alpha, \beta \in Y$. This means that the tree R^* generated by $\{\tau_\alpha : \alpha \in Y\}$ belongs to \mathcal{F}_m . However, $R^* \subseteq R$ and R is orthogonal to all trees in \mathcal{F}_m , a contradiction. \square

3. THE FORCING $\partial^*(K)$

In this section we define a notion of forcing $\partial^*(K)$ and prove that it is proper. We then show that either there is an uncountable antichain Y in T such that $\wedge(Y) \cap K = \emptyset$ or forcing with $\partial^*(K)$ adds an uncountable subset X of $K_\varphi \cap T \upharpoonright C$ such that $\pi(X) = X$. Then it will be easy to force again and obtain an uncountable subset Z of X such that $\wedge(Z) \subseteq K$. Before we start it will be convenient to define a certain club of countable elementary submodels of $H(\omega_2)$. Fix, for each $\delta < \omega_1$, a surjection $e_\delta : \omega \rightarrow T_\delta$.

Definition 3.1. \mathcal{E} is the collection of all countable elementary submodels M of $H(\omega_2)$ such that $T, C, K, (e_\delta : \delta < \omega_1)$ as well as $(N_\xi^n : \xi \in C)$, for $n < \omega$, all belong to M .

We are now in the position to define the partial order $\partial^*(K)$.

Definition 3.2. $\partial^*(K)$ consists of all pairs (X_p, \mathcal{M}_p) such that:

- (1) X_p is a finite subset of $T \upharpoonright C$, $\pi(X_p) = X_p$, and $X_p \cap T_\alpha \in K_\varphi$, for all $\alpha \in \text{lev}(X_p)^2$.
- (2) \mathcal{M}_p is a finite \in -chain of elements of \mathcal{E} such that for every $x \in X_p$ there is $M \in \mathcal{M}_p$ such that $\text{ht}(x) = M \cap \omega_1$.

The order of $\partial^*(K)$ is the coordinatewise reverse inclusion, i.e. $q \leq p$ iff $X_p \subseteq X_q$ and $\mathcal{M}_p \subseteq \mathcal{M}_q$.

In what follows, for $p \in \partial^*(K)$, M_p^i denotes the i -th model in \mathcal{M}_p , in the enumeration induced by the heights of the models.

Theorem 3.3. $\partial^*(K)$ is a proper forcing notion.

Proof. Fix a countable $M \prec H(2^{|\partial^*(K)|^+})$ such that $\partial^*(K), \mathcal{E} \in M$. Given a condition $p = (X_p, \mathcal{M}_p) \in M$, we need to find $q \leq p$ that is $(\partial^*(K), M)$ -generic. Set

$$q = (X_p, \mathcal{M}_p \cup \{M \cap H(\omega_2)\}).$$

²Here, of course, we identify $X_p \cap T_\alpha$ with its \leq_{lex} -increasing enumeration.

We claim that q is as desired. To see this, fix a dense set $D \in M$ and a condition $r \leq q$. We need to find $s \in D \cap M$ which is compatible with r . By replacing r with a stronger condition we may assume that $r \in D$. Define

$$r' = (X_r \cap M, \mathcal{M}_r \cap M)$$

and

$$r^* = (X_r \setminus M, \mathcal{M}_r \setminus M)$$

Note that r' and r^* are both conditions in $\partial^*(K)$. Let $l = |\mathcal{M}_r \setminus M|$. For every $i < l$, let $\delta_i = M_{r^*}^i \cap \omega_1$, let $k_i = |X_{r^*} \cap T_{\delta_i}|$ and fix $\sigma_i \in [\omega]^{k_i}$ such that $e_{\delta_i}[\sigma_i] = X_{r^*} \cap T_{\delta_i}$. As before, we also think of $X_{r^*} \cap T_{\delta_i}$ as an element of $T^{[k_i]}$ via its \leq_{lex} -increasing enumeration. We now define formulas θ_i , for $i < l$, by reverse induction on i .

$\theta_l(\xi_0, \dots, \xi_{l-1})$ holds if there is a condition $s = (X_s, \mathcal{M}_s) \in \partial^*(K)$ such that:

- (1) $\mathcal{M}_s = \{M_s^0, \dots, M_s^{l-1}\}$,
- (2) $M_s^i \cap \omega_1 = \xi_i$, for all $i < l$,
- (3) $X_s \cap T_{\xi_i} = e_{\xi_i}[\sigma_i]$ and $|X_s \cap T_{\xi_i}| = k_i$, for all $i < l$,
- (4) $(X_{r'} \cup X_s, \mathcal{M}_{r'} \cup \mathcal{M}_s) \in D$.

Suppose θ_{i+1} has been defined for some $i < l$. Then

$$\theta_i(\xi_0, \dots, \xi_{i-1}) \text{ iff } Q\eta \theta_{i+1}(\xi_0, \dots, \xi_{i-1}, \eta).$$

Here $Q\eta \theta(\eta)$ means “there are stationary many η such that $\theta(\eta)$ holds”.

Remark 3.4. Notice that the parameters of each $\theta_i(\xi_0, \dots, \xi_{i-1})$ are in M , so if $\xi_0, \dots, \xi_{i-1} \in M$ then $\theta_i(\xi_0, \dots, \xi_{i-1})$ holds iff it holds in M . Thus, if W_i is the set of tuples $(\xi_0, \dots, \xi_{i-1})$ such that $\theta_i(\xi_0, \dots, \xi_{i-1})$ holds then $W_i \in M$, for all $i \leq l$. We set $W = \bigcup_{i \leq l} W_i$.

Notice also that if $\theta_i(\xi_0, \dots, \xi_{i-1})$ holds then $e_{\xi_j}[\sigma_j] \in K_\varphi^{[k_j]}$, for all $j < i$.

Claim 3.5. $\theta_i(\delta_0, \dots, \delta_{i-1})$ holds, for all $i \leq l$.

Proof. We prove this by reverse induction on i . Notice that $\theta_l(\delta_0, \dots, \delta_{l-1})$ holds as witnessed by the condition r^* . Suppose we have established $\theta_{i+1}(\delta_0, \dots, \delta_i)$. Since $W_{i+1} \in M \cap H(\omega_2)$ and $M \cap H(\omega_2) = M_{r^*}^0 \subseteq M_{r^*}^i$ it follows that the set

$$Z = \{\eta : (\delta_0, \dots, \delta_{i-1}, \eta) \in W_{i+1}\}$$

also belongs to $M_{r^*}^i$. If Z were non stationary, by elementarity, there would be a club $E \in M_{r^*}^i$ disjoint from it, but $\delta_i \in Z$ and δ_i belongs to any club which is in $M_{r^*}^i$, a contradiction. \square

By Claim 3.5 we can pick a *stationary splitting tree* $U \subseteq W$. This means that $U \subseteq (\omega_1)^{\leq l}$ is a tree and for every node $t = (\xi_0, \dots, \xi_{i-1}) \in U$ of height $i < l$ the set

$$S_t = \{\eta : (\xi_0, \dots, \xi_{i-1}, \eta) \in U\}$$

is stationary. We can moreover assume that $U \in M$. We now build by induction an increasing sequence $(\xi_i : i < l)$ of ordinals in M such that:

- (1) $(\xi_0, \dots, \xi_i) \in U$, for all i ,
- (2) $e_{\xi_i}[\sigma_i] \cup e_{\delta_0}[\sigma_0] \upharpoonright \xi_i \in K_\varphi^{[k_i+k_0]}$, for all i .

The reason we require (2) is that we want the condition s witnessing the formula $\theta_l(\xi_0, \dots, \xi_{l-1})$ to be compatible with r and this is the only problem we may encounter. Now, suppose $j < l$ and we have picked ξ_i , for all $i < j$. Consider the set $S_j = \{\eta : (\xi_0, \dots, \xi_{j-1}, \eta) \in U\}$.

Claim 3.6. *There is $\xi \in S_j \cap M$ such that $e_\xi[\sigma_j] \cup e_{\delta_0}[\sigma_0] \upharpoonright \xi \in K_\varphi^{[k_j+k_0]}$.*

Proof. Assume otherwise. We know that S_j is stationary and that the level sequence $\mathcal{S}_j = \{e_\eta[\sigma_j] : \eta \in S_j\}$ is contained in $K_\varphi^{[k_j]}$. By shrinking S_j we may also assume that \mathcal{S}_j is regular. Let

$$Z = \{\eta : e_\eta[\sigma_0] \in K_\varphi^{[k_0]} \wedge \forall \xi \in S_j \cap \eta [e_\xi[\sigma_j] \cup e_\eta[\sigma_0] \upharpoonright \xi \notin K_\varphi^{[k_j+k_0]}\}\}.$$

Then $Z \in M$ and since by our assumption $\delta_0 \in Z$, it follows that Z is stationary. By shrinking Z , we may assume that the level sequence $\mathcal{Z} = \{e_\eta[\sigma_0] : \eta \in Z\}$ is regular. Now, by Lemma 2.10 and MA_{\aleph_1} we obtain a contradiction. \square

Suppose $(\xi_0, \dots, \xi_{l-1})$ has been constructed. Since $(\xi_0, \dots, \xi_{l-1}) \in U \cap M$, by elementarity there is a condition $s \in \partial^*(K) \cap M$ witnessing this fact. Let

$$\bar{s} = (X_{r'} \cup X_s, \mathcal{M}_{r'} \cup \mathcal{M}_s).$$

Then by (4) in the statement of $\theta_l(\xi_0, \dots, \xi_{l-1})$ we know that $\bar{s} \in D$. Since s and r' are both in M so is \bar{s} . We claim that \bar{s} is compatible with r . To see this we define a condition u as follows. Let

$$X_u = \pi(X_r \cup X_s).$$

Note that $\text{lev}(X_u) = \text{lev}(X_{r'}) \cup \text{lev}(X_s) \cup \text{lev}(X_{r^*})$ and we have

$$X_u \cap T_\alpha = \begin{cases} e_{\delta_i}[\sigma_i] & \text{if } \alpha = \delta_i, \text{ for some } i < l, \\ e_{\xi_i}[\sigma_i] \cup e_{\delta_0}[\sigma_0] \upharpoonright \xi_i & \text{if } \alpha = \xi_i, \text{ for some } i < l, \\ X_{r'} \cap T_\alpha & \text{if } \alpha \in \text{lev}(X_{r'}). \end{cases}$$

In all cases we have that $X_u \cap T_\alpha \in K_\varphi$. We let $\mathcal{M}_u = \mathcal{M}_{r'} \cup \mathcal{M}_s \cup \mathcal{M}_{r^*}$. It follows that $u \leq \bar{s}, r$. This completes the proof of Theorem 3.3. \square

4. THE MAIN THEOREM

In this section we complete the proof of the main theorem saying that the conjunction of BPFA and φ implies CAT. Let G be V -generic over the poset $\partial^*(K)$ and define in $V[G]$:

$$X_G = \bigcup \{X_p : p \in G\}.$$

Note that $\pi(X_G) = X_G$, $\text{lev}(X_G) \subseteq C$, and every finite subset of X_G contained in one level of T is in K_φ . Let \dot{X}_G be a canonical $\partial^*(K)$ -name for X_G . We first establish the following fact in the ground model V .

Lemma 4.1. *Suppose there is no uncountable antichain Y in T such that $\wedge(Y) \cap K = \emptyset$. Then there is a condition $p \in \partial^*(K)$ which forces that \dot{X}_G is uncountable.*

Proof. Suppose the maximal condition forces that \dot{X}_G is countable. Let θ be a sufficiently large regular cardinal and let M be a countable elementary submodel of $H(\theta)$ containing all the relevant objects. As shown in Theorem 3.3 $q = (\emptyset, \{M \cap H(\omega_2)\})$ is an $(M, \partial^*(K))$ -generic condition. Therefore, $q \Vdash \dot{X}_G \subseteq M$. If there is a node t in $K_\varphi^{[1]} \cap T_\delta^{[1]}$ then $r = (\{t\}, \{M \cap H(\omega_2)\})$ is a condition stronger than q and $r \Vdash t \in \dot{X}_G$, a contradiction. Assume now that $T_\delta^{[1]} \subseteq L_\varphi^{[1]}$. Since δ is a limit point of C , by Fact 2.5 there is an uncountable antichain Y in T such that $\wedge(Y) \cap K = \emptyset$, again a contradiction. \square

Now, assume there is no uncountable antichain $Y \subseteq T$ such that $\wedge(Y) \cap K = \emptyset$ and fix a V -generic G over $\partial^*(K)$ containing a condition as in Lemma 4.1. We work in $V[G]$. We can show that $\text{lev}(X_G)$ is a club, but this is not necessary. Namely, let \bar{X}_G be the closure of X_G in the tree topology. Then by Fact 2.6 all finite subsets of \bar{X}_G contained in one level of T are in K_φ . Moreover, $\text{lev}(\bar{X}_G)$ is equal to the closure of $\text{lev}(X_G)$ in the order topology and is a club. Clearly, we also have $\pi(\bar{X}_G) = \bar{X}_G$.

Remark 4.2. Before continuing it is important to note a certain amount of absoluteness between V and $V[G]$. In V we defined $(\mathcal{F}_n)^V$ to be the collection of regular subtrees R of $T^{[n]}$ such that $\wedge(R) \cap K^{[n]} = \emptyset$. The same definition in $V[G]$ gives a larger collection $\mathcal{F}_n^{V[G]}$ of subtrees of $T^{[n]}$. Nevertheless, the definition of \mathcal{F}_n is Σ_1 with parameters T and K . Since BPFA holds in V , if a certain tree $A \in V$ is in $(\mathcal{F}_n^V)^\perp$ then it is also in $(\mathcal{F}_n^{V[G]})^\perp$. It follows that the same sequences $(N_\xi^n : \xi \in C)$ witness $\varphi(\mathcal{F}_n)$ in V and in $V[G]$, for all n . Therefore the definitions of the induced colorings $K_\varphi^{[n]}$, for $n < \omega$, are also absolute between V and $V[G]$.

Definition 4.3. *The poset \mathcal{Q} consists of finite antichains p in \bar{X}_G such that $\wedge(p) \subseteq K$, ordered by reverse inclusion.*

Claim 4.4. *\mathcal{Q} is a c.c.c. poset.*

Proof. Suppose \mathcal{A} is an uncountable subset of \mathcal{Q} . We need to find two elements of \mathcal{A} which are compatible. By a standard Δ -system argument we may assume that the elements of \mathcal{A} are disjoint and have the same size. For each $\alpha \in \text{lev}(\bar{X}_G)$ choose $p_\alpha \in \mathcal{A}$ such that $\text{ht}(t) \geq \alpha$, for all $t \in p_\alpha$. We can assume that the p_α are distinct. Let σ_α be the enumeration in \leq_{lex} -increasing order of distinct elements of $\{t \upharpoonright \alpha : t \in p_\alpha\}$. There is a stationary subset S of $\text{lev}(\bar{X}_G)$ and an integer n such that σ_α has size n , for all $\alpha \in S$. Note that $\sigma_\alpha \in K_\varphi^{[n]}$, for all $\alpha \in S$. By shrinking S further we may assume that $\{\sigma_\alpha : \alpha \in S\}$ is a regular level sequence and that for every $\alpha, \beta \in S$ and every distinct $i, j < n$

$$\sigma_\alpha(i) \wedge \sigma_\beta(j) = \sigma_\alpha(i) \wedge \sigma_\alpha(j) \in K.$$

Now, by Fact 2.7 we can find distinct $\alpha, \beta \in S$ such that $\sigma_\alpha \wedge \sigma_\beta \in K^{[n]}$, i.e. $\sigma_\alpha(i) \wedge \sigma_\beta(i) \in K$, for all $i < n$. It follows that p_α and p_β are compatible in \mathcal{Q} . \square

By a standard argument there is a condition $q \in \mathcal{Q}$ which forces the \mathcal{Q} -generic H to be uncountable. Therefore, by forcing with \mathcal{Q} below q over $V[G]$ we obtain an uncountable antichain H of T such that $\wedge(H) \subseteq K$. Since $\partial^*(K) * \mathcal{Q}$ is proper, by BPFA, we have such an antichain in V . Thus, we have proved the main theorem which we now state.

Theorem 4.5. *Assume BPFA and φ . Then CAT holds and hence there is a five element basis for the uncountable linear orders.* \square

REFERENCES

- [1] Uri Abraham and Saharon Shelah. Isomorphism types of Aronszajn trees. *Israel J. Math.*, 50(1-2):75–113, 1985.
- [2] James Baumgartner. Applications of the Proper Forcing Axiom. In K. Kunen and J. Vaughan, editors, *Handbook of Set-Theoretic Topology*. North-Holland, 1984.
- [3] James E. Baumgartner. A new class of order types. *Ann. Math. Logic*, 9(3):187–222, 1976.
- [4] James E. Baumgartner. Bases for Aronszajn trees. *Tsukuba J. Math.*, 9(1):31–40, 1985.
- [5] James E. Baumgartner. All \aleph_1 -dense sets of reals can be isomorphic. *Fund. Math.*, 79(2):101–106, 1973.
- [6] Keith J. Devlin. *Constructibility*. Perspectives in Mathematical Logic. Springer-Verlag, Berlin, 1984.
- [7] Martin Goldstern and Saharon Shelah. The Bounded Proper Forcing Axiom. *J. Symbolic Logic*, 60(1):58–73, 1995.

- [8] Thomas Jech. *Set theory*. Perspectives in Mathematical Logic. Springer-Verlag, Berlin, second edition, 1997.
- [9] Bernhard König, Paul Larson, Justin Tatch Moore, and Boban Veličković Bounding the consistency strength of a five element linear basis. *Israel J. Math.*, 164(1):1–18, 2005.
- [10] J. Tatch Moore. Structural analysis of Aronszajn trees. Proceedings of the 2005 Logic Colloquium, Athens, Greece.
- [11] Justin Tatch Moore. A five element basis for the uncountable linear orders. *Ann. of Math. (2)*, 163(2):669–688.
- [12] Justin Tatch Moore. Set mapping reflection. *J. Math. Log.*, 5(1):87–97, 2005.
- [13] Saharon Shelah. Decomposing uncountable squares to countably many chains. *J. Combinatorial Theory Ser. A*, 21(1):110–114, 1976.
- [14] Stevo Todorčević. Lipschitz maps on trees. report 2000/01 number 13, Institut Mittag-Leffler.
- [15] Stevo Todorčević. Trees and linearly ordered sets. In *Handbook of set-theoretic topology*, pages 235–293. North-Holland, Amsterdam, 1984.
- [16] Stevo Todorčević. Localized reflection and fragments of PFA. In *Logic and scientific methods*, volume 259 of *DIMACS Ser. Discrete Math. Theoret. Comput. Sci.*, pages 145–155. AMS, 1997.
- [17] Stevo Todorčević. Coherent sequences. In *Handbook of Set Theory*. North-Holland, (forthcoming).
- [18] Stevo Todorčević. Partitioning pairs of countable ordinals. *Acta Math.*, 159(3-4): 261–294, 1987

E-mail address: boban@math.univ-paris-diderot.fr

URL: <http://www.logique.jussieu.fr/~boban>

E-mail address: gio.venturi@gmail.com

IMJ-PRG, UNIVERSITÉ PARIS DIDEROT, 75205 PARIS CEDEX 13, FRANCE