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SUBSETS OF SUPERSTABLE STRUCTURES ARE WEAKLY BENIGN

BEKTUR BAIZHANOV, JOHN T. BALDWIN, AND SAHARON SHELAH

Baizhanov and Baldwin [1] introduce the notions of benign and weakly benign sets to investigate the preservation of stability by naming arbitrary subsets of a stable structure. They connect the notion with work of Baldwin, Benedikt, Bouscaren, Casanovas, Poizat, and Ziegler. Stimulated by [1], we investigate here the existence of benign or weakly benign sets.

- DEFINITION 0.1. (1) *The set A is benign in M if for every $\alpha, \beta \in M$ if $p = \text{tp}(\alpha/A) = \text{tp}(\beta/A)$ then $\text{tp}_*(\alpha/A) = \text{tp}_*(\beta/A)$ where the $*$ -type is the type in the language L^* with a new predicate P denoting A .*
- (2) *The set A is weakly benign in M if for every $\alpha, \beta \in M$ if $p = \text{stp}(\alpha/A) = \text{stp}(\beta/A)$ then $\text{tp}_*(\alpha/A) = \text{tp}_*(\beta/A)$ where the $*$ -type is the type in language with a new predicate P denoting A .*

CONJECTURE 0.2 (too optimistic). *If M is a model of stable theory T and $A \subseteq M$ then A is benign.*

Shelah observed, after learning of the Baizhanov-Baldwin reductions of the problem to equivalence relations, the following counterexample.

LEMMA 0.3. *There is an ω -stable rank 2 theory T with $ndop$ which has a model M and set A such that A is not benign in M .*

PROOF. The universe of M is partitioned into two sets denoted by Q and R . Let Q denote $\omega \times \omega$ and R denote $\{0, 1\}$. Define $E(x, y, 0)$ to hold if the first coordinates of x and y are the same and $E(x, y, 1)$ to hold if the second coordinates of x and y are the same. Let A consist of one element from each $E(x, y, 0)$ -class and one element of all but one $E(x, y, 1)$ -class such that no two members of A are equivalent for either equivalence relation. It is easy to check that letting α and β denote the two elements of R , we have a counterexample. In this case, the type p is algebraic. Algebraicity is a completely artificial restriction. Replace each α and β by an infinite set of points which behave exactly as α, β respectively. We still have a counterexample. In either case, α and β have different strong types. This leads to the following weakening of the conjecture. ⊣

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CONJECTURE 0.4 (Revised). *If M is a model of stable theory T and A is an arbitrary subset of M then A is weakly benign.*

We give here a proof of Conjecture 0.4 in the superstable case. There are two steps. In the first we show that if (M, A) is not (weakly) benign then there is a certain configuration within M . (This uses only T stable.) The second shows that this configuration is contradicted for superstable T . Note that if (M, A) is not weakly benign, neither is any L^* -elementary extension of (M, A) so we may assume any counterexample is sufficiently saturated.

§1. Refining a counterexample. In this section we choose a specific way in which a sufficiently saturated pair (M, A) where $\text{Th}(M)$ is stable, fails to be weakly benign. Fix M , a κ^+ -saturated model of a stable theory T where $\kappa = \kappa^{|T|}$ is regular.

We introduce some notation. Recall that A is *relatively κ -saturated* in M if every type over (a subset of A) whose domain has cardinality less than κ and which is realized in M , is also realized in A . First note that for any $c \in M - A$, there is a pair (M_1, A_1) such that A_1 is relatively κ -saturated in A ; $A_1 \cup c \subseteq M_1$ and M_1 is independent from A over A_1 ; A_1 and M_1 have cardinality κ and M_1 is κ -saturated. For this, choose $A_0 \subset A$ with c independent from A over A_0 and $|A_0| < \kappa$ (which follows since $\kappa \geq |T|^+ \geq \kappa(T)$). Then extend A_0 to a subset A_1 of A with cardinality at most κ which is relatively κ -saturated in A . Finally, let $M_1 \prec M$ be κ -prime over $A_1 \cup c$. We have shown the following class \mathbf{K}_c is not empty.

NOTATION 1.1. (1) *For any $c \in M$, let \mathbf{K}_c be the class of pairs (M_1, A_1) with $c \in M_1 \prec M$ such that A_1 is relatively κ -saturated in A ; $A_1 \cup c \subseteq M_1$ and M_1 is independent from A over A_1 ; A_1 and M_1 have cardinality κ and M_1 is κ -saturated with $|M_1| \leq \kappa$.*

(2) *For any a, b in M which realize the same type over A , let $\mathbf{K}_{a,b}^1$ be the set of tuples $\langle A_1, M_a, M_b, N_a, g \rangle$ such that (M_a, A_1) and (M_b, A_1) are in $\mathbf{K}_a, \mathbf{K}_b$ respectively, g is an isomorphism between M_a and M_b (subsets of M) over A_1 (taking a to b), N_a contains M_a and is saturated with cardinality κ , and N_a is independent from A over A_1 .*

(3) *Let $\mathbf{K}_{a,b}^2$ be the set of tuples $\langle A_1, M_a, M_b, N_a, g \rangle \in \mathbf{K}_{a,b}^1$ such that g is an isomorphism between M_a^{eq} and M_b^{eq} over A_1^{eq} (taking a to b). a and b realize the same type over A_1^{eq} , so they realize the same strong type over A_1 .*

(4) *We will write K^i to denote either K^1 or K^2 . Note the only difference between them is that K^2 has a more restrictive requirement on the isomorphism g .*

Note that the last clause of item 2 implies that N_a is independent from A over $N_a \cap A$ and that $N_a \cap A = A_1 = M_a \cap A$. Moreover, if $\langle A_1, M_a, M_b, N_a, g \rangle \in \mathbf{K}_{a,b}$ and $B \subseteq A$ with $|B| \leq \kappa$ then there is an $\langle A'_1, M'_a, M'_b, N'_a, g' \rangle \in \mathbf{K}_{a,b}$ with $A_1 \cup B \subseteq A'_1$. (Just include B when making the construction from the first paragraph of this section to show $\mathbf{K}_{a,b}$ is nonempty). We need a couple of other properties of $\mathbf{K}_{a,b}$. Note that $\mathbf{K}_{a,b}$ is naturally partially ordered by coordinate by coordinate inclusion.

LEMMA 1.2. *Every increasing chain from $\mathbf{K}_{a,b}^i$ of length δ a limit ordinal less than κ^+ has an upper bound in $\mathbf{K}_{a,b}^i$.*

PROOF. If the cofinality of the chain is at least κ , just take the union (in each coordinate). We check that N_a^δ, A are independent over A^δ : By induction, for every

$\alpha < \beta < \delta$, $tp(N_a^\alpha/A)$ does not fork over A_1^β (by monotonicity of nonforking). Hence if δ is a limit ordinal, $tp(N_a^\delta/A)$ does not fork over A_1^δ .

But if the cofinality is smaller the union may not preserve κ -saturation. In this case, let $\langle A'_1, M'_a, M'_b, N'_a, g' \rangle$ denote the union of the respective chains; each has cardinality κ . Choose $A_1 \subseteq A$ with $|A_1| = \kappa$ and such that A_1 is relatively κ -saturated in A and A_1 contains A'_1 . Then let the bound be $\langle A_1, M_a, M_b, N_a, g \rangle$ where M_a is κ -prime over $M'_a \cup A_1$, M_b is κ -prime over $M'_b \cup A_1$, g is the induced isomorphism extending g' and N_a is any κ -saturated elementary extension of $M_a \cup N'_a$ in M with N_a independent from A over A_1 . \dashv

LEMMA 1.3. *If $t = \langle A_1, M_a, M_b, N_a, g \rangle \in \mathbf{K}_{a,b}^i$ and $p \in S(M_a)$ is non-algebraic, orthogonal to A and $p \not\perp tp(N_a/M_a)$, then there is $t' = \langle A'_1, M'_a, M'_b, N'_a, g' \rangle \in \mathbf{K}_{a,b}^i$ with t' extending t and $tp(N_a/M'_a)$ forking over M_a .*

PROOF. Since M is κ^+ -saturated, we can find $d \in M$ realizing p such that $tp(d/N_a)$ forks over M_a and $d' \in M$ realizing $g(p)$. Now, construct t' by letting $A'_1 = A_1$, M'_a be κ -prime over $M_a \cup \{d\}$, M'_b be κ -prime over $M_b \cup \{d'\}$, g' be an extension of g taking d to d' , and $N'_a \prec M$ any κ -saturated extension of $M'_a \cup N_a$. We need to show that M'_a and M'_b are independent from A over A'_1 . For this, note that since $p \in S(M_a)$ is orthogonal to A (*a fortiori* to A_1) and A is independent from M_a over A_1 , d is independent from A over M_a . Since M'_a is κ -prime over $M_a \cup \{d\}$, it follows that M'_a is independent from A over A'_1 . An analogous argument shows M'_b is independent from A over A'_1 . Since $d \in M'_a$, we have fulfilled the lemma. \dashv

For any ordinal μ and any sequence $\langle \mathbf{a}_i : i < \mu \rangle$ and any finite $w \subseteq \mu$, \mathbf{a}_w denotes $\langle \mathbf{a}_i : i \in w \rangle$. We require one further technical notion.

DEFINITION 1.4. *We say M_a is A -full in M if for any N κ -prime over M_a and for any $C_0 \subseteq M_a$, $|C_0| \leq |T|$, $C_1 \subseteq A$ with $|C_1| \leq |T|$, and C_2 with $C_0 \subseteq C_2$, $C_1 \subseteq C_2 \subseteq N$, and $|C_2| \leq |T|$, there is an elementary map f taking $C_1 C_2$ into M_a over C_0 with $f(C_1) \subseteq A$ and if C_2 is independent from A over C_1 then $f(C_2)$ is independent from A over $f(C_1)$.*

We prove a characterization of a weakly benign pair; a similar result for benign (using \mathbf{K}^1 instead of \mathbf{K}^2) also holds. In view of the counterexample in given in the introduction, weakly benign is the interesting case.

LEMMA 1.5. *Use the notation of 1.1. Suppose (M, A) is κ^+ -saturated where $\kappa = \kappa^{|T|}$ is regular and $T = \text{Th}(M)$ is stable. The following are equivalent.*

- (1) (M, A) is not weakly benign.
- (2) There exist A_* , M_a, N_a, M_b, g contained in M with $a \in M_a, b \in M_b$ such that:
 - (a) $\langle A_*, M_a, M_b, N_a, g \rangle \in \mathbf{K}_{a,b}^2$ and $M_a \neq N_a$.
 - (b) M_a is A -full in M .
 - (c) $tp(N_a/M_a)$ is orthogonal to every nonalgebraic type in $S(M_a)$ which is orthogonal to A .
 - (d) If $\mathbf{d} \in N_a - M_a$, there is no $\mathbf{d}' \in M$ which realizes $g(tp(\mathbf{d}/M_a))$ and such that \mathbf{d}' is independent from A over M_b .

We can easily deduce from condition a) that N_a is independent from A over A_* and also that M_a and M_b are isomorphic over A_* by a map g taking a to b and preserving strong types over A , i.e., $g \upharpoonright (A^*)^{\text{eq}}$ is the identity. By general properties

of orthogonality, we could rephrase item c) as: $\text{tp}(N_a/M_a)$ is orthogonal to every nonalgebraic type in $S(M_a)$ which is orthogonal to A_* .

PROOF OF LEMMA 1.5. First we show that condition (2) implies condition (1). By condition (2a), there is an a' in $N_a - M_a$. Note that since A^* is relatively κ^+ -saturated in A and $M_a(M_b)$ is independent from A over A^* , $M_a \cap A = M_b \cap A = A^*$. It follows that $g \cup (\text{id} \upharpoonright \text{acl}(A^{\text{eq}}))$ is an elementary map in L^{eq} . Let $\mathbf{a} = \langle a_i : i < \kappa \rangle$ enumerate $M_a - A$ with $a_0 = a$; denote $g(a_i)$ by b_i so $\mathbf{b} = \langle b_i : i < \kappa \rangle$ enumerates M_b . For any finite set of L -formulas Δ and finite subset w of κ , let $\phi_{\Delta,w}(\mathbf{x}; a', \mathbf{a}_w, \mathbf{b}_w)$ be the L^* -formula which asserts that $x\mathbf{b}_w$ and $a'\mathbf{a}_w$ realize the same Δ -type over A . For any finite w , \mathbf{a}_w and \mathbf{b}_w realize the same L -type over A .

Now, let $q = \{ \phi_{\Delta,w}(\mathbf{x}; a', \mathbf{a}_w, \mathbf{b}_w) : 0 \in w \subset_{\omega} \kappa, \Delta \subset_{\omega} L \}$. Putting $0 \in w$ guarantees a, b are in any relevant $\mathbf{a}_w, \mathbf{b}_w$. So q is a set of κ L^* -formulas with free variable x and parameters from $M_a \cup M_b \cup \{a'\}$. If q is finitely satisfied in (M, A) , then q is realized in M by some b' , since M is κ^+ -saturated as an L^* -structure. But since a' is independent from A over M_a , b' realizes the unique nonforking extension of $g(\text{tp}(a'/M_a))$ to $M_b \cup A$ contradicting condition d). If q is not finitely satisfiable, there is a formula $\phi_{\Delta,w}$ which demonstrates the L^* type of \mathbf{a}_w and \mathbf{b}_w over A are different.

We will use the following basic fact (compare Lemma I.1.12 of [2]):

- FACT 1.6.** (1) *If A_1 is relatively κ -saturated in A and C is independent from A over A_1 , then CA_1 is relatively κ -saturated in CA .*
 (2) *If A_1 is relatively κ -saturated in A and D is κ -atomic over A_1 , D is independent from A over A_1 .*

To show (1) implies (2) of Lemma 1.5, we suppose that \mathbf{a} and \mathbf{b} realize the same (strong)-type over A but that there is an a' such that there is no $b' \in M$ with $\mathbf{a}a' \equiv_{A,L} \mathbf{b}b'$. We fix $\langle a, b \rangle$ as the \mathbf{a}, \mathbf{b} and analyze $\mathbf{K}_{a,b}^2$ below.

LEMMA 1.7. *There is a $t = \langle A_*, M_a, M_b, N_a, g \rangle \in \mathbf{K}_{a,b}^2$ such that*

- (A) $N_a \neq M_a$,
 (B) $\text{tp}(N_a/M_a)$ is orthogonal to every nonalgebraic type in $S(M_a)$, which is orthogonal to A .
 (C) *If $\mathbf{d} \in N_a - M_a$, there is no $\mathbf{d}' \in M$ which realizes $g(\text{tp}(\mathbf{d}/M_a))$ and such that \mathbf{d}' is independent from A over M_b .*
 (D) M_a is A -full.

PROOF. Try to construct by induction a sequence $\langle t_\alpha : \alpha < \kappa^+ \rangle$ where $t_\alpha = \langle A_*^\alpha, M_a^\alpha, M_b^\alpha, N_a^\alpha, g^\alpha \rangle$ of elements of $\mathbf{K}_{a,b}^2$ which are increasing in the natural partial order, continuous at limit ordinals of cofinality greater than $\kappa_r(T)$; t_0 is any element of $\mathbf{K}_{a,b}^2$ with $a' \in N_a^0$.

- (1) If α is an even ordinal there are several cases.
 (a) Suppose condition (B) fails, i.e. for some $d \in N_a$, $p = \text{tp}(d/M_a)$ is nonorthogonal to some stationary type $q \in S(M_a)$ which is orthogonal to A . Then by Lemma 1.3, there is $t' = \langle A_*', M_a', M_b', N_a', g' \rangle \in \mathbf{K}_{a,b}^2$ with t' extending t and $\text{tp}(N_a/M_a')$ forks over M_a .
 (b) Suppose condition (B) holds.
 (i) If α is a limit ordinal of cofinality κ , stop.

(ii) If α is a limit ordinal of cofinality $< \kappa$ or α is a successor ordinal, let

$$t_{\alpha+1} = t_\alpha.$$

- (2) α is an odd successor ordinal. Choose an auxiliary \hat{M}_a^α κ -prime over $M_a^\alpha A$. Choose $A_*^{\alpha+1}, M_a^{\alpha+1}, M_b^{\alpha+1}$ such that $A_*^\alpha \subseteq A_*^{\alpha+1} \subseteq A$, $|A_*^{\alpha+1}| = \kappa$ and so that

$$(M_a^{\alpha+1}, A_*^{\alpha+1}) \prec_{L_{(|T|+|T|+)}} (\hat{M}_a^\alpha, A)$$

and $M_a^{\alpha+1}$ is κ -prime over $M_a^\alpha A_*^{\alpha+1}$. This is possible since $\kappa = \kappa^{|T|}$. In particular, $M_a^{\alpha+1}$ is independent from A over $A_*^{\alpha+1}$. The κ -primeness allows us to easily construct $M_b^{\alpha+1}$ and $g_{\alpha+1}$. Now choose $N_a^{\alpha+1}$ to be a κ -saturated extension of $M_a^{\alpha+1}$ that is independent from A over $A_*^{\alpha+1}$.

- (3) If α is a limit ordinal choose t_α by Lemma 1.2.

We cannot carry out this construction for κ^+ steps. If we did, by clause (1) of the construction at each limit α with $\text{cf}(\alpha) = \kappa$, clause (B) fails. Thus, $M_a^{\alpha+1}$ depends on N_a^α over M_a^α for all such α , which contradicts stability. (If we were dealing with finite sequences, the bound would be $\kappa(T)$; since we deal with sets of cardinality κ , the bound is κ^+ .)

Fix α where the construction stops. We have constructed $t_\alpha = \langle A_*^\alpha, M_a^\alpha, M_b^\alpha, N_a^\alpha, g^\alpha \rangle$ but for any choice of $t_{\alpha+1} \in \mathbf{K}_{a,b}^2$, $M_a^{\alpha+1}$ is independent from N_a^α over M_a^α . Note that each member of $t_\alpha = \langle A_*^\alpha, M_a^\alpha, M_b^\alpha, N_a^\alpha, g^\alpha \rangle$ is the union of the respective member of t_β over $\beta < \alpha$. We claim this t_α is a t satisfying the conditions of the lemma.

For clause (A) note $N_a^\alpha \neq M_a^\alpha$ since $a' \in N_a^\alpha$ and a' cannot be in the domain of g^α by the original choice of a' . Since the construction stopped clause (B), holds.

For clause (C), we must show that if $\mathbf{d} \in N_a - M_a$, there is no $\mathbf{d}' \in M$ which realizes $g(\text{tp}(\mathbf{d}/M_a))$ and such that \mathbf{d}' is independent from A over M_b . Fix $\mathbf{d} \in N_a - M_a$; if such a \mathbf{d}' exists, choose $M_a^{\alpha+1}, M_b^{\alpha+1}$ contained in M prime over $M_a^\alpha \mathbf{d}$ and $M_b^\alpha \mathbf{d}'$ respectively. We easily extend g^α to $g^{\alpha+1}$ mapping $M_a^{\alpha+1}$ to $M_b^{\alpha+1}$. By the construction, A_*^α is relatively κ -saturated in A . So, $M_a^\alpha \cup \{\mathbf{d}\}$ and A are independent over A_*^α by monotonicity, as N_a^α is independent from A over A_*^α . Now by Fact 1.6 (1), $M_a^\alpha \cup \{\mathbf{d}\}$ is relatively κ -saturated inside $M_a^\alpha \cup \{\mathbf{d}\} \cup A$. Whence, by Fact 1.6 (2) $M_a^{\alpha+1}$ and A are independent over $M_a^\alpha \cup \{\mathbf{d}\}$. By transitivity of nonforking, $M_a^{\alpha+1}$ and A are independent over A_*^α . Similarly, since \mathbf{d}' is independent from A over M_b , $M_b^{\alpha+1}$ is independent from A over A_*^α . But now, N_a^α depends on $M_a^{\alpha+1}$ over M_a^α because $d \in (M_a^{\alpha+1} \cap N_a^\alpha) - M_a^\alpha$ and we have violated the choice of α .

Finally we verify clause (D): M_a is A -full. Choose N , which is κ -prime over AM_a . Then N can be embedded over AM_a into $\hat{M}_a^\alpha = \cup_{i < \alpha} \hat{M}_a^i$. By the Tarski union of chains theorem (using clause (2) of the construction), $(M_a^\alpha, A \cap M_a^\alpha) \prec_{L_{(|T|+|T|+)}} (\hat{M}_a^\alpha, A)$. Let $C_0, C_1, C_2 \subseteq N$ satisfy the hypotheses of the definition of A -full. The elementary submodel condition easily allows us to define the required function f . +

And thus, we have proved Lemma 1.5. +

§2. The superstable case. The aim of this section is to prove that if M is a model of a superstable theory and $A \subset M$, then (M, A) is weakly benign. This is a

generalization of a result of Bouscaren [3], who showed, in our terminology that every *submodel* of a superstable structure is benign.

THEOREM 2.1. *If M is a model of a superstable theory and $A \subset M$, then (M, A) is weakly benign.*

PROOF. We work in \mathcal{M}^{eq} . Without loss of generality, assume (M, A) is κ^+ -saturated for a regular κ satisfying $\kappa^{|T|} = \kappa$. By Lemma 1.5 if (M, A) is not weakly benign, there exist A_*, M_a, N_a, M_b, g contained in M satisfying the conditions of Lemma 1.5 and with $\langle A_*, M_a, M_b, N_a, g \rangle \in \mathbf{K}_{a,b}^2$.

Since M_a is properly contained in N_a , we can choose $\mathbf{c} \in M_a$ and $\phi(x, \mathbf{c})$ to have minimal D -rank among all formulas with $\phi(N_a, \mathbf{c}) \neq \phi(M_a, \mathbf{c})$. Then for any $d^* \in \phi(N_a, \mathbf{c}) \setminus \phi(M_a, \mathbf{c})$, $p^* = \text{tp}(d^*/M_a)$ is regular. Without loss of generality again, we can fix d^* , which does not fork over \mathbf{c} and so that p^* has the same D -rank as $\phi(x, \mathbf{c})$ and $\text{tp}(d^*/\mathbf{c})$ is stationary. By clause (c) of Lemma 1.5, p^* is not orthogonal to A_* . So, there is a $q' \in S(M_a)$ which does not fork over A_* and is nonorthogonal and so non-weakly orthogonal to p^* . Fix $C \subseteq A_*$ with $|C| \leq |T|$ and \mathbf{c} is independent from A_* over C . Without loss of generality $\text{tp}(d^*/A_*\mathbf{c}) \not\perp^w q' \upharpoonright (A_*\mathbf{c})$ and $\text{tp}(d^*/C\mathbf{c}) \not\perp^w q' \upharpoonright (C\mathbf{c})$. Let $\mathcal{P} = \{p : p \text{ is regular, stationary, and nonorthogonal to } p^*\}$. \mathcal{P} is based on $B = \text{acl}^{\text{eq}}(C)$, i.e. every automorphism of \mathcal{M} fixing B maps \mathcal{P} to itself.

If $\mathbf{c}'' \in M$ realizes $\text{tp}(\mathbf{c}/A^{\text{eq}})$ and $d''\mathbf{c}''$ realizes $r = \text{tp}(d^*\mathbf{c}/B)$, then $\text{tp}(d''/\mathbf{c}'')$ is regular and nonorthogonal to p^* . We can find $\langle \mathbf{c}_i : i < \omega \rangle$ in M_a with $\mathbf{c}_0 = \mathbf{c}$ which are indiscernible over B and which are based on B . The $r(\mathbf{x}, \mathbf{c}_i)$ are regular, pairwise nonorthogonal, and all nonorthogonal to \mathcal{P} and each $r(\mathbf{x}, \mathbf{c}_i)$ is not weakly orthogonal to $q' \upharpoonright (B\mathbf{c}_i)$. Note $r(\mathbf{x}, \mathbf{c}_i) \subset p^*$. Let $r_i \in S(M)$ denote the nonforking extension of $r(\mathbf{x}, \mathbf{c}_i)$ to $S(M)$. By Section V.4 of [4], there is a $q \in S(B)$, which is \mathcal{P} -simple and $k < \omega$ such that $w_{\mathcal{P}}(q) > 0$ and $q(\mathcal{M}) \subseteq \text{acl}(B \cup \bigcup_{i < k} \mathbf{c}_i \cup \bigcup_{i < k} r(\mathcal{M}, \mathbf{c}_i))$. (This q is actually q'/E for an appropriate definable (over B) equivalence relation; compare V.4.17 (8) of [4].)

Let q^+ denote the unique nonforking extension of q to $S(M)$, p_a^+ denote the unique nonforking extension of p^* to $S(M)$, and p_b^+ denote the unique nonforking extension of $g(p^*)$ to $S(M)$. Clearly, $p_a^+ \upharpoonright (M_a \cup A)$ is a nonforking extension of the stationary type p^* and is realized by \mathbf{d}^* ; so it is equivalent to $p_a^+ \upharpoonright \text{acl}(M_a \cup A)$.

REMARK 2.2. Note $(g \cup \text{id}_A)(p_a^+ \upharpoonright (M_a \cup A) = p_b^+ \upharpoonright (M_b \cup A) \sim p_b^+ \upharpoonright \text{acl}(M_b \cup A)$ is omitted in M .

We use the next lemma several times.

LEMMA 2.3. *If $A^{\text{eq}} \subseteq N_1 \subseteq N_2 \subseteq M$ and N_1, N_2 are $|T|^+$ -saturated then*

$$w_{\mathcal{P}}(q(N_2), N_1) = w_{\mathcal{P}}(q(N_2), q(N_1)A^{\text{eq}}).$$

PROOF. Fix $\mathbf{b} \in N_1$ and choose $D \subseteq q(N_1)A^{\text{eq}}$ with $|D| \leq |T|$ such that $\text{tp}(\mathbf{b}/q(N_1)A^{\text{eq}})$ does not fork over D . If $\text{tp}(\mathbf{b}/q(N_2)A^{\text{eq}})$ forks over D , there are finite $\mathbf{d}_1 \subseteq q(N_2)$ and $\mathbf{d}_2 \subseteq A^{\text{eq}}$ such that $\text{tp}(\mathbf{b}/B\mathbf{d}_1\mathbf{d}_2)$ forks over D . But there is a $\mathbf{d}' \in q(N_1)$ realizing $\text{stp}(\mathbf{d}_1/D\mathbf{d}_2)$, which contradicts $\text{tp}(\mathbf{b}/q(N_1)A^{\text{eq}})$ does not fork over D .

So $\text{tp}(\mathbf{b}/q(N_2)A^{\text{eq}})$ does not fork over $q(N_1)A^{\text{eq}}$. Since \mathbf{b} was arbitrary in N_1 , $\text{tp}(N_1/q(N_2)A^{\text{eq}})$ does not fork over $q(N_1)A^{\text{eq}}$. By symmetry of forking, $\text{tp}(q(N_2)/N_1A^{\text{eq}})$ does not fork over $q(N_1)A^{\text{eq}}$. Since $A^{\text{eq}} \subseteq N_1$ we finish. \dashv

The proof now proceeds by a series of claims. The key idea is that $w_{\mathcal{F}}(q(M), A^{\text{eq}})$ can be calculated either as $w_{\mathcal{F}}(q(M), q(M_b) \cup A^{\text{eq}}) + w_{\mathcal{F}}(q(M_b), A^{\text{eq}})$ or $w_{\mathcal{F}}(q(M), q(M_a) \cup A^{\text{eq}}) + w_{\mathcal{F}}(q(M_a), A^{\text{eq}})$. We will calculate both ways to obtain a contradiction. We begin with the M_a side.

CLAIM 2.4. *If $\dim(r_0 \upharpoonright A_* \mathbf{c}_0, M_a)$ is finite, then $w_{\mathcal{F}}(q(M_a), A_* \cup \bigcup_{i < k} \mathbf{c}_i)$ is finite.*

PROOF. If u is a finite subset of ω , since the r_i are regular, it is easy to show that for each i , $\dim(r_i \upharpoonright (A_* \mathbf{c}_i), M_a)$ is finite iff $\dim(r_i \upharpoonright (A_* \cup \mathbf{c}_i \cup_{j \in u} \mathbf{c}_j), M_a)$ is finite. Since the $r_i \upharpoonright (A_* \mathbf{c}_i)$ are regular and pairwise not weakly orthogonal

$$\dim(r_i \upharpoonright A_* \mathbf{c}_i \mathbf{c}_j, M_a) = \dim(r_j \upharpoonright A_* \mathbf{c}_i \mathbf{c}_j, M_a).$$

The previous two sentences imply: $\dim(r_i \upharpoonright A_* \mathbf{c}_i, M_a)$ is finite iff $\dim(r_j \upharpoonright A_* \mathbf{c}_j, M_a)$ is finite. So if $\dim(r_0 \upharpoonright A_* \mathbf{c}_0, M_a)$ is finite then $w_{\mathcal{F}}(\bigcup_{i < k} r_i(M_a \cdot \mathbf{c}_i), A_* \cup \bigcup_{i < k} \mathbf{c}_i)$ is finite; whence $w_{\mathcal{F}}(q(M_a), A_* \cup \bigcup_{i < k} \mathbf{c}_i)$ is finite. \dashv

Now we drop the $\bigcup_{i < k} \mathbf{c}_i$ in the conclusion.

CLAIM 2.5. *$\dim(r_0 \upharpoonright A_* \mathbf{c}_0, M_a)$ is finite implies $w_{\mathcal{F}}(q(M_a), A_*)$ is finite.*

PROOF. Find $\mathbf{d} \subseteq q(M)$ such that $\bigcup_{i < k} \mathbf{c}_i$ is independent from $A_* \cup q(M)$ over $A_* \cup \mathbf{d}$. Now, as $\text{tp}(\mathbf{d}/A_*)$ is \mathcal{F} -simple, $w_{\mathcal{F}}(q(M_a), A_*) = w_{\mathcal{F}}(q(M_a), A_* \mathbf{d}) + w_{\mathcal{F}}(\mathbf{d}, A_*)$. The second term is finite and $w_{\mathcal{F}}(q(M_a), A_* \mathbf{d}) = w_{\mathcal{F}}(q(M_a), A_* \mathbf{d} \cup \bigcup_{i < k} \mathbf{c}_i)$ by the independence. But, $w_{\mathcal{F}}(q(M_a), A_* \mathbf{d} \cup \bigcup_{i < k} \mathbf{c}_i) = w_{\mathcal{F}}(q(M_a), A_* \cup \bigcup_{i < k} \mathbf{c}_i) - w_{\mathcal{F}}(\mathbf{d}, A_* \cup \bigcup_{i < k} \mathbf{c}_i)$. Now the first of the last two terms is finite by Claim 2.4 (since $\dim(r_0 \upharpoonright A_* \mathbf{c}_0, M_a)$ is finite) and the second by the finiteness of \mathbf{d} so $w_{\mathcal{F}}(q(M_a), A_*)$ is finite. \dashv

CLAIM 2.6. *$\dim(r_0, M_a)$ is finite.*

PROOF. Note that $p_a^+ \upharpoonright (\mathbf{Bc}_0) = r_0 \upharpoonright (\mathbf{Bc}_0)$. Choose by induction $\mathbf{a}_\alpha \in M_a$ so that \mathbf{a}_α realizes $p_a^+ \upharpoonright A_*^{\text{eq}} \cup g(\mathbf{c}_0) \cup \{\mathbf{a}_\beta : \beta < \alpha\}$ for as long as possible to construct: $\mathbf{I} = \langle \mathbf{a}_\alpha : \alpha < \alpha^* \rangle$. Clearly $\alpha^* < |M_a|^+$, but in fact α^* is finite. As, since M_a is independent from A over A_* , \mathbf{I} is a set of indiscernibles over A . Since M is κ^+ -saturated, if \mathbf{I} is infinite $\langle g(\mathbf{a}_\alpha) : \alpha < \alpha^* \rangle$ can be extended to a set \mathbf{J} of indiscernibles over A contained in M_b with cardinality κ^+ . Then all but at most κ members of \mathbf{J} realize $p_b^+ \upharpoonright (M_b \cup A)$ contradicting Remark 2.2 that $p_b^+ \upharpoonright (M_b \cup A)$ is omitted in M . \dashv

Now, easily we have

CLAIM 2.7. *$w_{\mathcal{F}}(q(M_a), A_*) = w_{\mathcal{F}}(q(M_a), A^{\text{eq}})$ is finite.*

PROOF. The equality holds by the independence of M_a and A over A_* . The finiteness follows from Claim 2.6 and Claim 2.5. \dashv

The next claim involves both M_a and M_b .

CLAIM 2.8. *Suppose $w_{\mathcal{F}}(q(M_a), A_*)$ is finite and $N \prec M$ is κ -prime over $M_b A$. Then $w_{\mathcal{F}}(q(N), q(M_b)A) = 0$.*

PROOF. Since $w_{\mathcal{F}}(q(M_a), A_*)$ is finite, and A, M_a are independent over A_* , we can choose finite $D \subseteq q(M_a)$ with $w_{\mathcal{F}}(q(M_a), A_*) = w_{\mathcal{F}}(q(M_a), A) = w_{\mathcal{F}}(D, A_*) = w_{\mathcal{F}}(D, A)$.

Now assume for contradiction that $w_{\mathcal{F}}(q(N), q(M_b)A) > 0$. Let $N' \prec M$ be κ -prime over $M_a \cup A$, so there is $g^+ \supseteq g \cup \text{id}_A$ which is an isomorphism from N' onto N . Then there is a finite $D_2 \subseteq q(N')$ with $w_{\mathcal{F}}(D_2, M_a A) > 0$. Choose $C_0 \subseteq M_a$, $|C_0| \leq |T|$ with $DB \subseteq C_0$ and $C_1 \subseteq A$ with $|C_1| \leq |T|$ so that D_2

is independent from $M_a A$ over $C_0 C_1$ and is the unique nonforking extension of $\text{tp}(D_2/C_0 C_1)$ to $S(M_a A)$ which is realized in M . Recall that M_a is A -full and apply the Definition 1.4 of A -full with $C_0 C_1 D_2$ playing the role of C_2 to obtain an embedding f . Then, $f(D_2) \subseteq q(M_a)$ and $f(D_2)$ is independent from $C_0 A$ over $C_0 f(C_1)$. Thus,

$$w_{\mathcal{F}}(f(D_2), AD) = w_{\mathcal{F}}(D_2, AD) \geq w_{\mathcal{F}}(D_2, q(M_a)A) > 0.$$

This implies $w_{\mathcal{F}}(q(M_a), A) \geq w_{\mathcal{F}}(Df(D_2), A) = w_{\mathcal{F}}(D, A) + w_{\mathcal{F}}(f(D_2), AD) > w_{\mathcal{F}}(D, A)$, which contradicts our original choice of D . \dashv

CLAIM 2.9. $w_{\mathcal{F}}(q(M), q(M_b)A) = 0$.

PROOF. Let $N \prec M$ be κ -prime over $M_b \cup A$, so $p_b^+ \upharpoonright (M_b \cup A)$ has a unique extension in $S(N)$. If $w_{\mathcal{F}}(q(M), N) > 0$ then for some $\mathbf{b} \in q(M)$, $w_{\mathcal{F}}(\mathbf{b}, N) > 0$ so $\text{tp}(\mathbf{b}/N) \not\perp p_b^+$: recall p_b^+ is parallel to $p_b^+ \upharpoonright N$. So $p_b^+ \upharpoonright N$ is realized in M_b contradicting Remark 2.2. Now $0 = w_{\mathcal{F}}(q(M), N)$ which equals $w_{\mathcal{F}}(q(M), q(N)A^{\text{eq}})$ by Lemma 2.3. Since $A^{\text{eq}} \subseteq N_b \subseteq N \subseteq M$,

$$\begin{aligned} w_{\mathcal{F}}(q(M), q(M_b)A^{\text{eq}}) &= w_{\mathcal{F}}(q(M), q(N)A^{\text{eq}}) + w_{\mathcal{F}}(q(N), q(M_b)A^{\text{eq}}) \\ &= 0 + 0 = 0. \end{aligned}$$

The first 0 was noted in the previous sentence and the second is Claim 2.8. \dashv

Now calculating with respect to M_b , we have:

CLAIM 2.10. $w_{\mathcal{F}}(q(M), A^{\text{eq}}) = w_{\mathcal{F}}(q(M_b), A^{\text{eq}})$ is finite.

PROOF.

$$\begin{aligned} w_{\mathcal{F}}(q(M), A^{\text{eq}}) &= w_{\mathcal{F}}(q(M), q(M_b)A^{\text{eq}}) + w_{\mathcal{F}}(q(M_b), A^{\text{eq}}) \\ &= 0 + w_{\mathcal{F}}(q(M_b), A^{\text{eq}}) < \omega. \end{aligned}$$

The first equality holds by additivity [4] and Lemma 2.3, the second by Claim 2.9, and the third by the last observation. \dashv

Now we analyze using M_a .

CLAIM 2.11. $w_{\mathcal{F}}((q(M), q(M_a) \cup A) \geq 1$.

PROOF. $w_{\mathcal{F}}(\mathbf{d}^*, M_a \cup A) \geq 1$ since \mathbf{d}^* is independent from A over M_a . Let N be κ -prime over $M_a A^{\text{eq}}$. As $\text{tp}(\mathbf{d}^*/M_a A^{\text{eq}})$ has all its restrictions to set of size less than κ realized in $M_a A^{\text{eq}}$, $\text{tp}(\mathbf{d}^*/N)$ does not fork over $M_a A^{\text{eq}}$. Thus, \mathbf{d}^* realizes $p_a^+ \upharpoonright N$. Since $p_a^+ \upharpoonright N$ is not orthogonal to $q^+ \upharpoonright N$, there is $\mathbf{b} \in q^+(M)$ which depends on \mathbf{b} over N . So $w_{\mathcal{F}}(\mathbf{b}, N) > 0$ whence $w_{\mathcal{F}}(q(M), N) > 0$. By monotonicity, $w_{\mathcal{F}}((q(M), q(M_a) \cup A) \geq w_{\mathcal{F}}(q(M), q(N)A^{\text{eq}})$. But, by Lemma 2.3, $w_{\mathcal{F}}(q(M), q(N)A^{\text{eq}}) = w_{\mathcal{F}}(q(M), N) > 0$. \dashv

Now we have

$$\begin{aligned} (1) \quad w_{\mathcal{F}}(q(M), A^{\text{eq}}) &= w_{\mathcal{F}}(q(M), q(M_a)A^{\text{eq}}) + w_{\mathcal{F}}(q(M_a), A^{\text{eq}}) \\ (2) \quad &\geq 1 + w_{\mathcal{F}}(q(M_a), A^{\text{eq}}) < \omega. \end{aligned}$$

Here, the first equality is by [4] and Lemma 2.3 and the second by Claim 2.11. The finiteness comes from Claim 2.7. Since $g \cup \text{id}_{A^{\text{eq}}}$ is an elementary map, $w_{\mathcal{F}}(q(M_a), A^{\text{eq}}) = w_{\mathcal{F}}(q(M_b), A^*)$. We substitute in Equation 1, using Claim 2.10:

$$w_{\mathcal{F}}(q(M_a), A^{\text{eq}}) = w_{\mathcal{F}}(q(M), A^{\text{eq}}) = w_{\mathcal{F}}(q(M_a), A^{\text{eq}}) + 1,$$

or subtracting, $0 = 1$ so we finish. \dashv

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