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## MORE ON REGULAR REDUCED PRODUCTS

JULIETTE CARA KENNEDY\* AND SAHARON SHELAH†

**Abstract.** The authors show, by means of a finitary version  $\square_{\lambda, D}^{\text{fin}}$  of the combinatorial principle  $\square_{\lambda}^{\text{fin}}$  of [7], the consistency of the failure, relative to the consistency of supercompact cardinals, of the following: for all regular filters  $D$  on a cardinal  $\lambda$ , if  $M_i$  and  $N_i$  are elementarily equivalent models of a language of size  $\leq \lambda$ , then the second player has a winning strategy in the Ehrenfeucht-Fraïssé game of length  $\lambda^+$  on  $\prod_i M_i/D$  and  $\prod_i N_i/D$ . If in addition  $2^i = \lambda^+$  and  $i < \lambda$  implies  $|M_i| + |N_i| \leq \lambda^+$  this means that the ultrapowers are isomorphic. This settles negatively conjecture 18 in [2].

The problem of when two elementarily equivalent structures have isomorphic ultrapowers was prominent in the model theory of the 1960's. Keisler [3] proved, assuming GCH, that elementarily equivalent structures have isomorphic ultrapowers. Keisler's proof depended on GCH both on the question of existence of good ultrafilters and on limiting the size of the ultrapowers. More exactly, Keisler considered a language of size  $\lambda$ , models  $M$  of size  $\leq \lambda^+$  and a  $\lambda^+$ -good countably incomplete ultrafilter  $D$  on  $\lambda$ . He proved that  $M^\lambda/D$  is  $\lambda^+$ -saturated. Under the weaker assumption that  $D$  is regular he proved that  $M^\lambda/D$  is  $\lambda^+$ -universal, i.e., every  $N \equiv M^\lambda/D$  of cardinality  $\leq \lambda$  can be elementarily embedded into it.

Shelah [6] improved the result by eliminating GCH: two structures  $M$  and  $N$  are elementarily equivalent if and only if, for some  $\lambda$  and some regular ultrafilter  $D$  on  $\lambda$  the structures  $M^\lambda/D$  and  $N^\lambda/D$  are isomorphic. This left open the following question, asked by Chang and Keisler as Conjecture 18 in [2]:

Let  $M$  and  $N$  be structures of cardinality  $\leq \lambda$  in a language of size  $\leq \lambda$  and let  $D$  be a regular ultrafilter over  $\lambda$ . If  $M \equiv N$ , then  $M^\lambda/D \cong N^\lambda/D$ .

The question is a natural one as most of the model theory regarding ultrapowers is centered on the regular ultrafilters. Also at the time of Keisler's question GCH was generally assumed, a reasonable assumption for the question.

Also the Conjecture is formulated for models of size  $\leq \lambda$ , perhaps for accidental reasons, but it seems more natural if  $M$  and  $N$  have cardinality  $\leq \lambda^+$ .

Conjecture 19 of [2], which we also address in this paper, is:

If  $D$  is a regular ultrafilter over  $\lambda$ , then for all infinite  $M$ ,  $M^\lambda/D$  is  $\lambda^{++}$ -universal.

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In [4] the authors proved that the transfer principle  $(\aleph_1, \aleph_0) \rightarrow (\lambda^+, \lambda)$  implies for all regular filters  $D$  on  $\lambda$

- (1)<sub>D</sub> For all  $M$  in a language of size  $\leq \lambda$ ,  $M^\lambda/D$  is  $\lambda^{++}$ -universal.  
 (2)<sub>D</sub> If  $M_i$  and  $N_i$  are elementarily equivalent models of a language of size  $\leq \lambda$ , then the second player has a winning strategy in the Ehrenfeucht-Fraïssé game of length  $\lambda^+$  on  $\prod_i M_i/D$  and  $\prod_i N_i/D$ .

Assuming  $2^\lambda = \lambda^+$ , (2)<sub>D</sub> yields the following corollary

- (2')<sub>D</sub> For  $M_i, N_i$  as in (2)<sub>D</sub> of cardinality  $\leq \lambda^+$ ,  $\prod_i M_i/D \cong \prod_i N_i/D$ .

We note that regularity is necessary for (1)<sub>D</sub>. I.e.,

LEMMA 1. *For any filter  $D$  on an infinite cardinal  $\lambda$ , if for all infinite  $N$  the structure  $N^\lambda/D$  is  $\lambda^{++}$ -universal, then  $D$  is regular.*

PROOF. For  $k = 1, 2$  let  $\mathcal{M}_k = \langle M_k, P_i^k \rangle_{i < \lambda}$ , where  $M_1 = \lambda$ ,  $M_2 = \lambda + 1$  and the  $P_i^k$  are defined as follows. Let  $k = 1$  and let  $D_0$  be a regular filter on  $\lambda$ . Let  $\{A_i\} \subseteq D_0$  witness the regularity of  $D_0$ . Thus for  $\alpha < \lambda$ ,  $\{i < \lambda \mid \alpha \in A_i\}$  is finite. Set  $P_i^1 = A_i$ . Now let  $k = 2$ . Let  $P_i^2 = A_i \cup \{\lambda\}$ . Now let  $D$  be any ultrafilter on  $\lambda$  and suppose there is an elementary embedding  $g$  mapping  $M_2$  into  $M_1^\lambda/D$ . Let  $g(\lambda) = [f]$  and let  $X_\alpha = \{i \mid f(i) \in P_\alpha^1\}$ . For each  $\alpha < \lambda$ ,  $a \in P_\alpha^2$  implies  $X_\alpha \in D$ . It is easy to see that  $\{X_\alpha\}_{\alpha < \lambda}$  is a regular family in  $D$ .  $\dashv$

We note that a similar argument can be used to show that (1)<sub>D</sub> fails if the language of  $M$  has size  $\lambda^+$ .

This was a partial answer to the above Conjectures 18 and 19. In this paper we show the converse for singular strong limit  $\lambda$ . Under GCH this is necessary as by Chang's Two Cardinal Theorem the transfer principle  $(\aleph_1, \aleph_0) \rightarrow (\lambda^+, \lambda)$  can only fail, in the presence of GCH, for singular  $\lambda$ . It is known that  $(\aleph_1, \aleph_0) \rightarrow (\aleph_{\omega+1}, \aleph_\omega) + \text{GCH}$  is consistent relative to the consistency of a supercompact cardinal [1]. It follows that the statement (2)<sub>D</sub> is independent of ZFC relative to the consistency of supercompact cardinals. On the other hand  $(\aleph_1, \aleph_0) \rightarrow (\lambda^+, \lambda)$  holds for all  $\lambda$  if  $V = L$ .

In fact we show more. The results of [4] were obtained using a finitary version, denoted here by  $\square_{\lambda, D}^{\text{fin}}$ , of the combinatorial principle  $\square_\lambda^{b^*}$  from [7], which is equivalent for all  $\lambda$  to  $(\aleph_1, \aleph_0) \rightarrow (\lambda^+, \lambda)$ . We showed in [4] that whenever  $\lambda$  is singular strong limit,  $\square_{\lambda, D}^{\text{fin}}$  is actually equivalent to  $\square_\lambda^{b^*}$ , using Theorem 2.3 and Remark 2.5 of [7]. Thus  $\square_{\lambda, D}^{\text{fin}}$  is equivalent to  $(\aleph_1, \aleph_0) \rightarrow (\lambda^+, \lambda)$ , again for  $\lambda$  singular strong limit. The consistency of e.g.,  $\text{GCH} + \neg \square_\lambda^{b^*}$  follows. Precisely we showed:

LEMMA 2. *Let  $D$  be a regular filter on  $\lambda$  where  $\lambda$  is a singular strong limit cardinal. Then  $\square_{\lambda, D}^{\text{fin}}$  implies  $\square_\lambda^{b^*}$ .*

The final piece needed for obtaining the transfer principle from (1)<sub>D</sub>, (2)<sub>D</sub> and (2')<sub>D</sub> for singular strong limit  $\lambda$  involves proving their equivalence with the principle  $\square_{\lambda, D}^{\text{fin}}$ , which equivalence is proved for all  $\lambda$  (Theorem 4).

We note that (2)<sub>D</sub> is more robust than what was originally conjectured, i.e., we have given a condition on when player II has a winning strategy in the EF game of length  $\lambda^+$  on the two structures  $\prod_i M_i/D$  and  $\prod_i N_i/D$ . Thus again if  $\lambda$  is singular strong limit, then the model theoretic (1)<sub>D</sub> and (2)<sub>D</sub> are equivalent to the set theoretic  $(\aleph_1, \aleph_0) \rightarrow (\lambda^+, \lambda)$ .

We need the following definition, from Lemma 4 of [4]:

**DEFINITION 3.** *Let  $D$  be a regular filter on  $\lambda$ . If there exist sets  $u_i^\zeta$  and integers  $n_i$  for each  $\zeta < \lambda^+$  and  $i < \lambda$  such that for each  $i, \zeta$*

- (i)  $|u_i^\zeta| < n_i$ ,
- (ii)  $u_i^\zeta \subseteq \zeta$ ,
- (iii) *Let  $B$  be a finite set of ordinals and let  $\zeta$  be such that  $B \subseteq \zeta < \lambda^+$ . Then  $\{i : B \subseteq u_i^\zeta\} \in D$ .*
- (iv) *Coherence:  $\gamma \in u_i^\zeta \Rightarrow u_i^\gamma = u_i^\zeta \cap \gamma$ ,*

*then we say that  $\square_{\lambda, D}^{fin}$  holds.*

Our main result:

**THEOREM 4.** *Assume  $\lambda \geq \aleph_0$  and  $D$  is a regular filter on  $\lambda$ . Then the following conditions are equivalent:*

- (i)  $\square_{\lambda, D}^{fin}$ .
- (ii) *If  $M_i$  and  $N_i$  are elementarily equivalent models of a language of cardinality  $\leq \lambda$ , then the second player has a winning strategy in the Ehrenfeucht-Fraïssé game of length  $\lambda^+$  on  $\prod_i M_i/D$  and  $\prod_i N_i/D$ .*
- (iii) *If  $M$  and  $N$  are structures of a language of cardinality  $\leq \lambda$ ,  $N \equiv M^\lambda/D$  and  $|N| \leq \lambda^+$ , then there is a homomorphism<sup>1</sup>  $N \rightarrow M^\lambda/D$ .*
- (iv) *If  $\Delta$  is a set of quantifier-free formulas and  $M^\lambda/D$  satisfies every existential  $\Delta$ -sentence (i.e., a sentence of the form  $\exists \vec{x}(\phi_1 \wedge \dots \wedge \phi_n)$ , where each  $\phi_i$  is in  $\Delta$ ) true in  $N$ ,  $|N| \leq \lambda^+$ , then there is a  $\Delta$ -homomorphism  $N \rightarrow M^\lambda/D$ , i.e., a homomorphism  $N \rightarrow M^\lambda/D$  which preserves  $\Delta$  formulas.*

*Additionally, if  $D$  is an ultrafilter, then (i)–(iv) are equivalent to*

- (v) *If  $M$  is a structure in a language of cardinality  $\leq \lambda$ , then  $M^\lambda/D$  is  $\lambda^{++}$ -universal.*

**PROOF.** (i)  $\rightarrow$  (ii), (i)  $\rightarrow$  (iii) and (i)  $\rightarrow$  (iv) follow from the “ $\Delta$ -existential” version of Theorem 2 of [4] which gives a  $\Delta$ -homomorphism of  $N$  into  $M^\lambda/D$  for any set  $\Delta$  of first-order formulas such that every  $\Delta$ -existential sentence true in  $N$  is true in  $M$ . If  $D$  is an ultrafilter, [4] gives (i)  $\rightarrow$  (v) and, on the other hand, (v)  $\rightarrow$  (iii) is straightforward.

(ii)  $\rightarrow$  (iii): It follows from  $N \equiv M^\lambda/D$  that there are  $M_0 \equiv M$  and a homomorphism  $N \rightarrow M_0$  such that  $M_0$  has cardinality  $\leq \lambda^+$ . By (ii) the second player has a winning strategy in the Ehrenfeucht-Fraïssé game of length  $\lambda^+$  on  $M_0^\lambda/D$  and  $M^\lambda/D$ . Using this winning strategy we get easily a homomorphism  $N \rightarrow M^\lambda/D$ .

(iii)  $\rightarrow$  (iv): Let  $M$  and  $N$  be as in (iv). Let  $N^*$  be an expansion of  $N$  obtained by giving a name to every  $\Delta$ -definable relation. Let  $(M^\lambda/D)^*$  be obtained similarly from  $M^\lambda/D$ . Let  $M_0^* \equiv (M^\lambda/D)^*$  such that there is a homomorphism  $N^* \rightarrow M_0^*$ . (The existence of such  $M_0^*$  follows from the fact that we can find  $M_0^* \equiv (M^*)^\lambda/D$  and a homomorphism  $N^* \rightarrow M_0^*$ . But then  $(M^*)^\lambda/D$  is canonically embeddable into  $(M^\lambda/D)^*$ .) By (iii) there is a homomorphism  $M_0^* \rightarrow M^\lambda/D$ . Thus there is a  $\Delta$ -homomorphism  $N \rightarrow M^\lambda/D$ .

(iv)  $\rightarrow$  (i): Let  $\lambda, D$  be given and let  $\tau$  denote a language of cardinality  $\leq \lambda$ . It suffices to prove the following

<sup>1</sup>I.e., a mapping  $N \rightarrow M^\lambda/D$  which respects the functions and relations of  $N$ .

CLAIM. There exist  $M, N$  such that

- (a)  $|M| = \lambda, |N| = \lambda^+$
- (b)  $\tau_M = \tau_N$  and  $|\tau_N| \leq \lambda$
- (c)  $M \equiv N$
- (d) For  $\Delta =$  the quantifier free formulas of  $\tau_M$ ,  $N$  has a  $\Delta$ -homomorphism into  $M^\lambda/D$ , and hence  $\square_{\lambda, D}^{fin}$  holds.

PROOF. Let  $\tau^* = \{F_\alpha \mid \alpha < \lambda\} \cup \{\langle \cdot \rangle\}$ , for  $F_\alpha$  a unary function symbol. Let  $K$  be the family of all structures  $M^*$  such that

- $K(1)$   $M^*$  is a finite  $\tau^*$ -structure.
- $K(2)$  The universe of  $M^*$  is  $\{0, 1, \dots, k-1\}$ , for some  $k \in \mathbb{N}$ , denoted  $\eta(M^*)$ .
- $K(3)$   $M^* \models \forall x (F_\alpha(x) \leq x)$  for all  $\alpha < \lambda$ .
- $K(4)$  If  $m_1 = F_{\alpha_1}^{M^*}(m)$ ,  $m_2 = F_{\alpha_2}^{M^*}(m)$  and  $m_1 < m_2$ , then there exists a unique  $\beta < \lambda$  such that  $m_1 = F_\beta^{M^*}(m_2)$ .
- $K(5)$  If  $F_{\alpha_2}^{M^*}(m_3) = m_2$ ,  $F_{\alpha_1}^{M^*}(m_2) = m_1$  and  $m_1 < m_2 < m_3$ , then there exists  $\alpha_3 < \lambda$  such that  $F_{\alpha_3}^{M^*}(m_3) = m_1$ .
- $K(6)$   $w(M^*) =_{df} \{\alpha \mid F_\alpha^{M^*} \text{ is not the identity}\}$  is finite.

We note that  $K$  is non-empty, taking  $K$  to be, e.g., a one element structure. Let  $\{M_i \mid i < \lambda\}$  list  $K$ . We will add the  $M_i$  together into one structure. I.e., we define a model  $M^*$  for  $\tau = \tau^* \cup \{E\}$  such that

- ( $a_K$ ) The universe of  $M^* = \cup\{\{i\} \times M_i \mid i < \lambda\}$
- ( $b_K$ )  $E^{M^*} = \{\langle (i_1, m_1), (i_2, m_2) \rangle \mid m_1 < \eta(M_{i_1}), m_2 < \eta(M_{i_2}) \text{ and } i_1 = i_2\}$
- ( $c_K$ )  $<^{M^*} = \{\langle (i, m_1), (i, m_2) \rangle \mid m_1 < m_2 < \eta(M_i)\}$
- ( $d_K$ )  $F_\alpha^{M^*}(i, m) = \langle i, F_\alpha^{M_i}(m) \rangle$ .

Now for  $\rho < \lambda^+$  let  $h_\rho$  be a partial one to one function from  $\lambda$  onto  $\rho$ , and let  $\langle a_\rho \mid \rho < \lambda^+ \rangle$  be a set of new constant symbols.

SUBCLAIM. There is  $N^*$  such that

- (a)  $N^*$  is a  $\tau^{**}$  structure of cardinality  $\lambda^+$ , where  $\tau^{**} = \tau \cup \{a_\rho \mid \rho < \lambda^+\} \cup \{\bar{m}\}_{m \in M}$ ,
- (b)  $M^* \preceq N^* \upharpoonright \tau$ .
- (c)  $a_\rho E^{N^*} a_0$  for  $\rho < \lambda^+$ ,
- (d)  $a_\rho <^{N^*} a_\xi$ , for  $\rho < \xi < \lambda^+$ ,
- (e)  $N^* \models F_j(\bar{a}_\rho) = \bar{a}_\epsilon$ , if  $h_\rho(j) = \epsilon$ , for  $j < \lambda$  and  $\epsilon < \rho < \lambda^+$ ; if  $\rho, j$  are such that  $h_\rho(j)$  is undefined, let  $F_j$  be the identity on  $a_\rho$ .

PROOF OF THE SUBCLAIM. Let  $T = Th(M, \bar{m})_{m \in M} \cup \{a_\rho E a_0\}_{\rho < \lambda^+} \cup \{a_\rho < a_\xi \mid \rho < \xi < \lambda^+\} \cup \{F_j(a_\rho) = a_\epsilon \mid h_\rho(j) = \epsilon\}$ . We claim that  $T$  is consistent. To see this, let  $T_0 = \{\varphi_i(\bar{m})\}_{i=1, \dots, n} \cup \{a_\rho E a_0\}_{i=1, \dots, k} \cup \{a_{\epsilon_i} < a_{\zeta_i}\}_{i=1, \dots, l} \cup \{F_{\alpha_i}(a_{\mu_i}) = a_{\nu_i} \mid h_{\mu_i}(\alpha_i) = \nu_i\}_{i=1, \dots, m}$  be a finite part of  $T$ , where  $a_{i_1}, \dots, a_{i_k}$  and  $\bar{m}_{j_1}, \dots, \bar{m}_{j_l}$  are all the parameters occurring in  $T_0$ . Let  $I_0 = \{i \mid \text{for some } j = j_1 \dots, j_l, m_j = (i, a), i < \lambda, a < \eta(M_i)\}$ . We can find  $M_{i_0}, i_0 \in \lambda \setminus I_0$ , such that if we interpret the constants  $a_\rho$  in  $M_{i_0}$  and  $\bar{m}_{j_i}$  by  $m_{j_i} \in M$ , then this expansion of  $M$  is a model of  $T_0$  and thus  $T_0$  is consistent. The Subclaim is proved.

Now let  $N^*$  be as in claim 1 and let  $N = N^* \upharpoonright \tau_{M^*}$ . We note that the pair of structures  $N$  together with the  $M^*$  defined above satisfying ( $a_K$ )–( $d_K$ ), satisfy the hypothesis of Theorem 2-(iv), i.e.,  $(M^*)^\lambda/D$  satisfies every existential  $\Delta$ -sentence

true in  $N$  where  $\Delta =$  the quantifier-free formulas of  $\tau_{M^*}$ . This is because  $N \equiv M^*$  and these  $\Delta$ -sentences are preserved under reduced products. Therefore by (iv) there is a  $\Delta$ -homomorphism  $g: N \rightarrow (M^*)^\lambda/D$ . Let  $g(a_\rho)$  be denoted by  $f_\rho/D$ .

We are now ready to define the sets  $u_i^f$  referred to in (i)–(iv) of the condition  $\square_{\lambda,D}^{fn}$ . To this end, for  $\epsilon < \rho < \lambda^+$ ,  $\rho \geq \lambda$ , define

$$A_{\epsilon,\rho} = \{j < \lambda \mid M^* \models (f_\rho(j) > f_\epsilon(j)) \wedge F_{i(\epsilon,\rho)}(f_\rho(j)) = f_\epsilon(j)\},$$

where  $i(\epsilon, \rho) < \lambda$  denotes the unique value  $i$ , for  $\epsilon < \rho < \lambda^+$  and  $h_\rho(i) = \epsilon$ . Note that if  $\epsilon < \rho < \lambda^+$ ,  $\rho \geq \lambda$ , then  $A_{\epsilon,\rho} \in D$ , since  $(M^*)^\lambda/D \models (g(a_\epsilon) < g(a_\rho)) \wedge F_{i(\epsilon,\rho)}(g(a_\rho)) = g(a_\epsilon)$ .

For each  $\rho \in (\lambda, \lambda^+)$  and  $j \leq \lambda$  define

$$W_{\rho,j} = \{\epsilon < \rho \mid \epsilon \geq \lambda \text{ and } j \in A_{\epsilon,\rho}\}.$$

We claim that if  $u_j^\rho =_{df} W_{\rho,j}$  then  $\square_{\lambda,D}^{fn}$  holds.

**PROOF OF CLAIM.** First note that under the  $\Delta$ -homomorphism  $g: N \rightarrow (M^*)^\lambda/D$ , if  $M^j (= M^*)$  is the  $j$ -th “component” of the reduced product  $(M^*)^\lambda/D$ , then there is a unique  $i_0 = i_0(j)$ ,  $i_0 < \lambda$ , such that each image element  $f_\rho(j)/D$  belongs to the same equivalence class  $i_0 \times M_{i_0}$  of  $M^*$ . This justifies introducing the following notation for the proofs of (i)–(ii) and (iv) of  $\square_{\lambda,D}^{fn}$ : for fixed  $j$  and  $i_0 = i_0(j)$  as above, if  $f_\rho(j) = (i_0, m(i_0, \rho))$ , denote  $m(i_0, \rho)$  by  $f_\rho(j)$  itself.

(i), (ii):  $W_{\rho,j}$  is a finite subset of  $\rho$ :

$$\begin{aligned} \{\epsilon < \rho \mid \epsilon \geq \lambda \text{ and } j \in A_{\epsilon,\rho}\} &= \{\epsilon < \rho \mid \epsilon \geq \lambda \text{ and } M^* \models F_{i(\epsilon,\rho)}(f_\rho(j)) = f_\epsilon(j)\} \\ &= \{\epsilon < \rho \mid \epsilon \geq \lambda \text{ and } M_{i_0} \models F_{i(\epsilon,\rho)}^{M_{i_0}}(f_\rho(j)) = f_\epsilon(j)\}. \end{aligned}$$

But  $w(M_{i_0})$  is finite, and therefore so is  $W_{\rho,j}$ . Thus if  $n_i$  is taken to be  $w(M_{i_0})$  then (i) and (ii) of  $\square_{\lambda,D}^{fn}$  are satisfied.

(iv): (coherency) holds of  $W_{\rho,j}$ , i.e., if  $\rho_1 < \rho_2 < \lambda^+$  and  $j < \lambda$  is given, if  $\rho_1 \in W_{\rho_2,j}$  then  $W_{\rho_1,j} = W_{\rho_2,j} \cap \rho_1$ . Why? Let  $\alpha \in W_{\rho_1,j}$ . Then  $\lambda \leq \alpha < \rho_2$  and  $j \in A_{\alpha,\rho_1}$ . But then  $M^* \models F_{i(\alpha,\rho_1)}(f_{\rho_1}(j)) = f_\alpha(j)$  and therefore  $M_{i_0} \models F_{i(\alpha,\rho_1)}^{M_{i_0}}(f_{\rho_1}(j)) = f_\alpha(j)$ . (Recall that we let  $f_{\rho_1}(j)$  stand for both the element of  $M^*$  and of  $M_{i_0}$ .)  $\rho_1 \in W_{\rho_2,j}$  and therefore  $j \in A_{\rho_1,\rho_2}$ . This means  $M_{i_0} \models F_{i(\rho_1,\rho_2)}^{M_{i_0}}(f_{\rho_2}(j)) = f_{\rho_1}(j)$ . By the definition of  $M_{i_0}$ , there is  $\beta$  such that  $M_{i_0} \models F_\beta^{M_{i_0}}(f_{\rho_2}(j)) = f_\alpha(j)$ . But  $\beta = i(\alpha, \rho_2)$  and  $j \in A_{\alpha,\rho_2}$  and therefore  $\alpha \in W_{\rho_2,j}$ . For the other direction suppose  $\alpha \in W_{\rho_2,j} \cap \rho_1$ . Then  $\alpha \geq \lambda$  and  $j \in A_{\alpha,\rho_2}$ , i.e.,  $M_{i_0} \models F_{i(\alpha,\rho_2)}^{M_{i_0}}(f_{\rho_2}(j)) = f_\alpha(j)$ .  $\rho_1 \in W_{\rho_2,j}$  means that as before  $j \in A_{\rho_1,\rho_2}$ , i.e.,  $M_{i_0} \models F_{i(\rho_1,\rho_2)}^{M_{i_0}}(f_{\rho_2}(j)) = f_{\rho_1}(j)$ . But then since  $\alpha < \rho_1$ , there is  $\beta$  such that  $M_{i_0} \models F_\beta^{M_{i_0}}(f_{\rho_1}(j)) = f_\alpha(j)$ , i.e., as before  $j \in A_{\rho_1,j}$  and  $\alpha \in W_{\rho_1,j}$ .

To see that (iii) is satisfied, let  $B \subseteq \lambda^+$  be a finite set of ordinals such that  $B \cap \lambda = \emptyset$ , and let  $\rho$  be such that  $B \subseteq \rho < \lambda^+$ . We wish to show that  $\{j \mid B \subseteq W_{\rho,j}\} \in D$ . Let  $B = \{j_1, \dots, j_n\}$ . Recall that by (e) of the subclaim,  $N^* \models F_{i(j,\rho)}(a_\rho) = a_j$  whence

$$C_k = \{i \mid M \models F_{i(j_k,\rho)}(f_\rho(i)) = f_{j_k}(i)\} \in D,$$

for each  $k = 1, \dots, n$ . Also by definition if  $i \in C_k$  then  $i \in A_{j_k, \rho}$  whence  $j_k \in W_{\rho, i}$ . Thus  $C_1 \cap \dots \cap C_n \subseteq \{j \mid B \subseteq W_{\rho, j}\} \in D$ .

Now if we transfer the sets  $u_j^\rho$ ,  $\lambda \leq \rho < \lambda^+$  to all of  $\lambda^+$ , (iv) implies (i), proving the Claim. Thus Theorem 2 is proved.

**COROLLARY 5.** *Assume  $\lambda \geq \aleph_0$ ,  $2^\lambda = \lambda^+$  and  $D$  is a regular filter on  $\lambda$ . Then the following are equivalent:*

- (i)  $\square_{\lambda, D}^{fin}$ .
- (ii) *If  $M_i$  and  $N_i$ ,  $i < \lambda$ , are elementarily equivalent models of a language of cardinality  $\leq \lambda$ , and  $|M_i|, |N_i| \leq \lambda^+$  then  $\prod_i M_i/D \cong \prod_i N_i/D$ .*

**COROLLARY 6.** *GCH + the failure of properties (i)–(iv) of Theorem 4 for  $\lambda = \aleph_\omega$  is consistent relative to the consistency of supercompact cardinals.*

**PROOF.** Assume GCH and  $(\aleph_1, \aleph_0) \rightarrow (\aleph_{\omega+1}, \aleph_\omega)$ . It is well-known (cf. [2] Proposition 4.3.5) that there is a regular filter  $D$  on  $\aleph_\omega$  generated by  $\aleph_\omega$  sets. The principle  $\square_{\aleph_\omega}^{b^*}$  fails. Thus  $\square_{\aleph_\omega, D}^{fin}$  fails by [4]. By Theorem 4, (i)–(iv) fail for the regular filter  $D$ .  $\dashv$

A drawback of Corollary 6 is that it deals with filters rather than ultrafilters, which was originally the most interesting case. This case will be dealt with in a work in preparation.

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