

THE THEOREMS OF BETH AND CRAIG  
IN ABSTRACT MODEL THEORY,III:  
 $\Delta$ -LOGICS AND INFINITARY LOGICS  
SH113

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ABSTRACT. We give a general technique on how to produce counterexamples to Beth's definability (and weak definability) theorem. The method is then applied for various infinitary, cardinality quantifier logics and  $\Delta$ -closure of such logics.

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## §1 INTRODUCTION

For unexplained terms, background and history see the excellent representation in Makowsky [Ma]. We show that in many cases, Beth theorem and weak definability fail. This may seem less “obviously true, just need proof” now than in 1975, when this was done and should have been written. The reason is that then it was not unreasonable to think the subject will continue to produce counterexamples only. But, by Mekler Shelah [MkSh 166] it is consistent that the logic  $L(\exists^{\geq \aleph_1})$  has  $W.(= weak)$  Beth. By [Sh 199]  $INT(L(Q_{\leq \aleph_j}^{cf}), L(aa))$  holds and the Beth closure of  $L(Q_{\leq 2^{\aleph_0}}^{cf})$  (cofinality at most continuum) is compact.

In §2 we concentrate on counterexamples to  $W.$  Beth, and in §3 on counterexamples to Beth for  $\Delta$ -closure of  $L_{\infty, \omega}$ .

In §2 we gave sufficient conditions for the failure of Beth and Weak Beth (in 2.1-2.7). This involves  $Pr_{\mathcal{L}_1, \mathcal{L}_2}^x(\mu, \Theta, \sigma)$  (see Definition 2.1). So we deal with finding instances of those properties for logics of the form  $L_{\Theta, \kappa}$  (in 2.8) then discuss why we cannot have some desirable cases (see 2.9-2.12); we state our conclusion on the failure of Beth and Weak Beth for logics of the form  $L_{\Theta, \kappa}$  in 2.13. In 2.14-2.18 we look at properties of logics related to the properties existence of models with automorphisms.

In §3 we show  $\Delta$ -closures do not satisfy Beth. In 3.2-3.4 we give a sufficient (quite general) condition for the failure of Beth (or Weak Beth) for the  $\Delta$ -closure of  $\mathcal{L}$ , which include using a counterexample to interpolation  $(\sigma_1, \neg\sigma_2)$ .

In 3.3 we get specialized conclusion Beth theorem fail for  $(\mathcal{L}, \Delta(L_{\infty, \omega}))$  if in  $\mathcal{L}$  we can, essentially, have a pseudo elementary classes separating two regular cardinals as cofinality. For this we rely on the abstract theorem 3.4, but the main work is verifying the condition from there which is done in 3.13. Before this 3.6, give specific conclusion  $(L_{\omega_2, \omega}$  and  $L(\exists^{\geq \lambda})(\lambda = cf \lambda > \aleph_0)$  does not satisfy Beth even when we look for the explicit definition in  $\Delta(L_{\infty, \omega})$ . This is an example for the abstract conclusion:  $\Delta$ -interpolation does not imply Beth.

In the end 3.15, we use a forcing of Gitik to derive a universe where for regular  $\mu < \lambda$  even in  $\Delta(L_{\infty, \mu})$  we cannot find interpolants for  $L(\exists^{\geq \lambda})$  (or any  $\mathcal{L}$ ,  $L(\exists^{\geq \lambda}) \leq \Delta(\mathcal{L})$ ).

The main work as mentioned above is in 3.13; which is a kind of generalization of Morley omitting type theorem, this time controlling cofinalities of “many” orders (many — a set of linear orders indexed by sets which have to be large themselves); [for “few” orders see [Sh 18].

I thank Janos Makowsky for his many contributions to this) paper. The reader would do better to have a copy of [Ma]; (for Theorem 2.8 - [Sh 189]), for 2.10 - [Sh 133], [Sh 228], for 2.11(1) - [Sh 129], for 2.12 - [Sh 125], for 3.13 stage [G] : [\Sha , VII, §5], for 3.15 - Gitik [G].

A logic  $\mathcal{L}$  is a function such that for any vocabulary  $\tau$ ,  $\mathcal{L}(\tau)$  is a set of sentences (so for  $M$  a  $\tau$ -model and  $\psi \in \mathcal{L}(\tau)$ ,  $M \models \psi$  or  $M \models \neg\psi$ , this is preserved by isomorphism. If not said otherwise,  $\mathcal{L}$  is closed under the obvious operations:  $\wedge$ ,  $\neg$ ,  $\exists x$ , and substitution. Of course,  $\tau_1 \subseteq \tau_2 \Rightarrow \mathcal{L}[\tau_1] \subseteq \mathcal{L}[\tau_2]$  and  $\mathcal{L}$  commute with renaming relation and function symbols.

**1.1 Open Problems:** 1) W. Beth ( $L(\exists^{\geq \lambda})$ ) (i.e. provably in ZFC)?

2) for  $\kappa$  strong limit singular, (or weakly compact) is there  $\psi \in L_{\kappa^+, \omega}$  all whose models have cardinality  $\kappa$  and are  $L_{\infty, \kappa}$ -equivalent (but there are at least two)? (See [Sh 228]).

3) Is  $L(Q^{ec})$  (equal cofinality quantifier) compact?

(Note: 3.13 is an approximation: if we restrict ourselves to a suitable class of cardinals).

Recall:

**1.2 Definition.** : 1)  $M + N$  or  $[M, N]$  is the disjoint sum of  $M, N$  (e.g. consider them as structures of different sorts).

2) For logics  $\mathcal{L}_1, \mathcal{L}_2$  let  $PPP(\mathcal{L}_1, \mathcal{L}_2)$  (= pair preservation properties) means, that for models  $M, N$ ,  $Th_{\mathcal{L}_1}(M + N)$  is determined by  $\langle Th_{\mathcal{L}_1}(M), Th_{\mathcal{L}_2}(N) \rangle$ .

3) For logics  $\mathcal{L}_1, \mathcal{L}_2$   $INT(\mathcal{L}_1, \mathcal{L}_2)$  means: if  $\varphi_1 \in \mathcal{L}_1(\tau_1)$ ,  $\varphi_3 \in \mathcal{L}_1(\tau_2)$  and  $\models \varphi_1 \rightarrow \varphi_3$  then for some  $\varphi_2 \in \mathcal{L}_2(\tau_1 \cap \tau_2) : \models \varphi_1 \rightarrow \varphi_2$  and  $\models \varphi_2 \rightarrow \varphi_3$ .

4)  $\varphi = \varphi(P, \bar{R}) \in \mathcal{L}(\{P\} \cup \bar{R})$  is a Beth definition (W. Beth definition) if for every  $\bar{R}$ -model  $M$  there is at most one [exactly one]  $P^M \subseteq |M|$ ,  $(M, P) \models \varphi$ .

5) For logics  $\mathcal{L}_1, \mathcal{L}_2$ ,  $Beth(\mathcal{L}_1, \mathcal{L}_2)$  [or W. Beth  $(\mathcal{L}_1, \mathcal{L}_2)$ ] means that: if  $\varphi(P, \bar{R}) \in \mathcal{L}_1(\{P\} \cup \bar{R})$  is a Beth definition (W. Beth definition) of  $P$ , then some  $\psi(x, \bar{R}) \in \mathcal{L}_2(\bar{R})$  is an explicit definition of  $P$ , i.e.

$$M = (A, \bar{R}^M, P^M) \models \varphi \Rightarrow P^M = \{a : M \models \varphi[a, \bar{R}]\}.$$

6)  $INT(\mathcal{L})$  means  $INT(\mathcal{L}, \mathcal{L})$  and  $Beth(\mathcal{L})$  means  $Beth(\mathcal{L}, \mathcal{L})$  and  $W.Beth(\mathcal{L})$  means  $W.Beth(\mathcal{L})$ .

7)  $\mathcal{L}_1 \leq \mathcal{L}_2$  if for every vocabulary  $\tau$ ,  $\mathcal{L}_1(\tau) \subseteq \mathcal{L}_2(\tau)$ .

## §2 SUFFICIENT CONDITIONS FOR BETH FAILURE AND APPLICATIONS

**2.1 Definition.** 1)  $Pr_{\mathcal{L}_1, \mathcal{L}_2}^a(\mu, \theta, \sigma)$  [ $\mathcal{L}$  a logic,  $\sigma, \theta$  are infinite cardinals,  $\mu$  a cardinal] means: (compare with 1.2)

(\*) there is a sentence  $\psi \in \mathcal{L}_1$  such that:

- (i)  $\psi$  has only rigid models
- (ii)  $\psi$  has exactly  $\mu$  models up to isomorphism
- (iii) every model of  $\psi$  has cardinality  $\leq \theta$ , (remember  $\theta \geq \aleph_0$ )
- (iv)<sup>a</sup> there is  $M \models \psi$ , and  $a, b \in M, a \neq b$  such that  $(M, a) \equiv_{\mathcal{L}_2} (M, b)$
- (v) the vocabulary of  $\psi$  has cardinality  $< \sigma$ .

2)  $Pr_{\mathcal{L}_1, \mathcal{L}_2}^b(\mu, \theta, \sigma)$  means as in (1) replacing (iv)<sup>a</sup> by:

(iv)<sup>b</sup> there are models  $M_0, M_1$  of  $\psi$  not isomorphic but  $\mathcal{L}_2$ -equivalent (so  $\mu > 1$ ).

3)  $Pr_{\mathcal{L}_1, \mathcal{L}_2}^c(\mu, \theta, \sigma)$  means as in (1) when we replace (iv)<sup>a</sup> by:

(iv)<sup>c</sup> if  $M_1, M_2$  are models of  $\psi$  then  $M_1 \equiv_{\mathcal{L}_2} M_2$ .

4)  $Pr_{\mathcal{L}_1, \mathcal{L}_2}^d(\mu, \theta, \sigma)$  means as in (1) but instead (iv)<sup>a</sup>:

(iv)<sup>d</sup> we have: (iv)<sup>c</sup> and (iv)<sup>a</sup> for every  $M \models \psi$ .

**2.2 Observation.** 1) There is obvious monotonicity (in  $\mathcal{L}_1, \mathcal{L}_2, \theta, \sigma$ ); i.e. if  $\mathcal{L}_1 \leq \mathcal{L}'_1, \mathcal{L}_2 \geq \mathcal{L}'_2, \theta \leq \theta', \sigma \leq \sigma'$ , and  $x \in \{a, b, c, d\}$  then  $Pr_{\mathcal{L}_1, \mathcal{L}_2}^x(\mu, \theta, \sigma)$  implies  $Pr_{\mathcal{L}'_1, \mathcal{L}'_2}^x(\mu, \theta', \sigma')$ .

2)  $Pr_{\mathcal{L}_1, \mathcal{L}_2}^a(\mu, \theta)$  implies  $Pr_{\mathcal{L}_1, \mathcal{L}_2}^b(\mu', \theta)$  for some  $\mu', \mu \leq \mu' \leq \mu + \theta$ .

3) If  $\mu > 1$ ,  $Pr_{\mathcal{L}_1, \mathcal{L}_2}^c(\mu, \theta, \sigma)$  implies  $Pr_{\mathcal{L}_1, \mathcal{L}_2}^b(\mu, \theta, \sigma)$ .

4)  $Pr_{\mathcal{L}_1, \mathcal{L}_2}^d(\mu, \theta, \sigma)$  implies  $Pr_{\mathcal{L}_1, \mathcal{L}_2}^x(\mu, \theta, \sigma)$  for  $x = a, c$ .

*Proof.* 1) - 4). Use the same example.

**2.3 Theorem.** 1) If  $Pr_{\mathcal{L}_1, \mathcal{L}_3}^b(\mu, \theta, \sigma)$  and  $PPP(\mathcal{L}_2, \mathcal{L}_3)$  and  $L_{\sigma, \omega} \leq \mathcal{L}_1 \leq \mathcal{L}_2 \leq \mathcal{L}_3$  then  $Beth(\mathcal{L}_1, \mathcal{L}_2)$  fail.  
 2) Suppose  $Pr_{\mathcal{L}_1, \mathcal{L}_2}^a(1, \theta, \sigma)$ ,  $L_{\sigma, \omega} \leq \mathcal{L}_1 \leq \mathcal{L}_2 \leq \mathcal{L}_3$  and  $PPP(\mathcal{L}_2, \mathcal{L}_3)$  then  $W. Beth(\mathcal{L}_1, \mathcal{L}_2)$  fail.

*Proof.* 1) Let  $M$  be a model of  $\psi \in \mathcal{L}_1[\tau]$ . For simplicity assume  $\tau$  has no function symbols. We construct a  $\tau \cup \{P\}$ -structure  $B$  in the following way:  $B = M \times \{0\} \cup M \times \{1\}$ , i.e.  $B$  is the disjoint union of two copies of  $M$ .

For each  $n$ -ary relation symbol  $R \in \tau$  let  $R^M$  be its interpretation in  $M$ . Now we put  $R_i = \{((a_1, i), \dots, (a_n, i)) : (a_1, \dots, a_n) \in R^M\}$  and  $R^B = R_0 \cup R_1$ .  $P$  is a unary predicate and  $P^B = M \times \{0\}$ . (Alternatively, use multi-sorted models). Let  $F$  be a binary relation symbol not in  $\tau \cup \{P\}$ . Let  $\varphi$  be a  $\tau \cup \{P, F\}$ -sentence of  $\mathcal{L}_1$  expressing that:

- (1) Both, the relativized structure on  $P$  and on  $\neg P$  are models of  $\psi$ ;
- (2)  $F$  is a  $\tau$ -isomorphisms from  $P$  to  $\neg P$ ;
- (3)  $F$  is of order two, i.e.  $F^2$  is the identity on  $P$ .

Clearly,  $\varphi$  defines  $F$  implicitly, since  $\psi$  has only rigid models, by (i) of 2.1. So assume, for contradiction, that  $Beth(\mathcal{L}_1, \mathcal{L}_2)$  holds. Let  $\theta \in \mathcal{L}_2$  be an explicit definition of  $F$ . By 2.1(2),  $\psi$  have non-isomorphic models  $M, N$  that  $M \equiv_{\mathcal{L}_3} N$ . We use  $PPP(\mathcal{L}_2, \mathcal{L}_3)$  to conclude that

$$(*) \quad M + N \equiv_{\mathcal{L}_2} M + M$$

where the first sort represents the interpretation of  $P$  and the second sort the interpretation of  $\neg P$ . Clearly,  $M + M$  has an expansion satisfying  $\varphi$  and therefore  $\theta$  defines a  $\tau$ -isomorphisms between the two sorts. So  $(*)$  says that  $\theta$  also defines a  $\tau$ -isomorphism in  $M + N$ . This is expressed by a sentence in  $L_{\sigma, \omega}$  (as  $\sigma > |\tau|$ ) hence in  $\mathcal{L}$ . Therefore  $M \cong N$  contradicting the choice of  $M, N$ .

2) Like part (1) only in the end we use  $(M, a) \equiv_{\mathcal{L}_2} (M, b)$ ,  $a \neq b$  where  $M$  is (the) model of  $\psi$ .

*2.4 Remark.* The closure properties of the (set of sentences of the logics)  $\mathcal{L}_1$  are very weak: we use a conjunction of a sentence from  $L_{\sigma, \omega}$  (the isomorphism) and two copies of  $\psi$ .

**2.5 Theorem.** *If  $Pr_{\mathcal{L}_1, \mathcal{L}_3}^b(\mu, \theta, \sigma)$   $\kappa^+ \geq \sigma^+$ ,  $\mu^+ + \theta^+$ ,  $L_{\kappa^+, \omega} = \mathcal{L}_0 \leq \mathcal{L}_1 \leq \mathcal{L}_2 \leq \mathcal{L}_3$ ,  $PPP(\mathcal{L}_2, \mathcal{L}_3)$  then Weak Beth for  $(\mathcal{L}_1, \mathcal{L}_2)$  fail.*

*2.6 Remark.* 1) We assume (implicitly) the vocabulary consist of predicates and function symbols with finite arity.

If we want to delete this assumption we should demand in 2.1, for every model  $M$  of  $\varphi$ :

$$\|M\| + \sum \left\{ \left\{ \|R^M\| : R \text{ a predicate of } M \right\} + \sum_f |\{(\bar{a}, b) : F^M(\bar{a}) = b\}| : \right. \\ \left. F^M \text{ a function of } M \right\} \text{ is } \leq \theta.$$

2) We choose below a proof which does not require that  $\mathcal{L}_i$  are closed under infinitary operations just include  $L_{\kappa^+, \omega}$  and closure under: relativization for  $\mathcal{L}_1$  (definition of  $\psi_1$ ) and finitary operations for  $\mathcal{L}_2$  (see end of argument).

3) I do not see many closure requirements on  $\mathcal{L}$  (except isomorphism of vocabularies); only substitute in

$$\begin{array}{ccc} \exists x & \exists y & [\varphi(x, y) \wedge (\forall x') (x \leq x')]? \\ \text{one sort} & \text{second sort} & \text{first sort} \end{array}$$

*Proof of 2.5.* Let  $\psi$  exemplify  $Pr_{\mathcal{L}_1, \mathcal{L}_2}^b(\mu, \theta, \sigma)$ .

Let  $M_i (i < \mu)$  be a complete list up to isomorphism with no repetition of models of  $\psi$ , and each has vocabulary  $\tau$ , so  $|\tau| \leq \kappa$  (as  $|\tau| < \sigma$ ,  $\sigma \leq \kappa^+$ ) and without loss of generality  $M_0 \equiv_{\mathcal{L}_3} M_1$ . Without loss of generality the universe of each  $M_i$  is  $\{\beta : \alpha_i \leq \beta < \alpha_{i+1}\}$  and  $\langle \alpha_i : i \leq \mu \rangle$  is increasing continuous,  $\alpha_0 = 0$ . Let  $\alpha(*) = \alpha_\mu$ , so  $\alpha(*) < \kappa^+$ . Let us define a model  $M^*$ :

- (a)  $R^{M^*}$  ( $R$  a two place predicate) is  $\{ \langle i, \alpha \rangle : \alpha_i \leq \alpha < \alpha_{i+1} \text{ and } i < \mu \}$
- (b) if  $P$  is an  $n(P)$ -place predicate of  $\tau$ , then  $Q_P$  is an  $(n(P)+1)$ -place predicate and  $Q_P^M = \{ \langle i, a_1, \dots, a_{n(P)} \rangle : \langle a_1, \dots, a_{n(P)} \rangle \in P^{M_i} \}$
- (c) (similarly for every function symbol of  $F$ )
- (d)  $<^{M^*}$  is  $\{ \langle \alpha, \beta \rangle : \alpha < \beta < \alpha(*) \}$ .

Let  $\tau^*$  be the vocabulary of  $M^*$ . Let  $\psi_0 \in L_{\kappa^+, \omega}(\tau^*)$  characterize  $M^*$  up to isomorphism. Let  $[\tau_1, \tau_2]$  be the vocabulary of  $[N_1, N_2]$  when  $N_\ell$  has vocabulary  $\tau_\ell$  (e.g. each  $N_\ell$  finitely sorted). Let  $\psi_1 \in \mathcal{L}_1([\tau^*, \tau])$  be such that:

$$[N_1, N_2] \models \psi_1 \Leftrightarrow (N_1 \models \psi_0 \text{ and } N_2 \models \psi).$$

Let  $F$  be a new unary function, and let  $\psi_2, \psi_3 \in \mathcal{L}_{|\tau|+, \omega}([\tau^*, \tau] + \{F\})$  say:

$[N_1, N_2] \models \psi_2$  iff  $F$  as a one to one function from  $N_2$  into  $N_1$  and there is  $x \in N_1$  such that :  
 $\text{Rang } F = \{y : N_1 \models R[x, y]\}$  and for every predicate  $P$  of  $\psi$ , and  $a_1, \dots, a_{n(P)} \in N_2$ ,  
 $N_2 \models P(a_1, \dots, a_{n(P)})$  iff  
 $N_1 \models Q_P(x, F(a_1), \dots, F(a_{n(P)}))$   
(similarly for function symbols).

$[N_1, N_2] \models \psi_3$  iff  $F$  is as above, but the  $x$  there is  $<^{N_1}$ -first.

Now every model of  $\psi_1$  can be expanded uniquely to a model of  $\psi_2$  (equivalently to a model of  $\psi_1 \wedge \psi_2$ ):

however,  $[M^*, M_0] \equiv_{\mathcal{L}_1} [M^*, M_1]$  as  $M_0 \equiv_{\mathcal{L}_3} M_1$  (by  $(iv)^b$  of Definition 2.1(2) and  $PPP(\mathcal{L}_1, \mathcal{L}_3)$ ). If some  $\varphi(x, y) \in \mathcal{L}_2[\tau^*, \tau]$  define  $F$  for models of  $\psi_1$  (as would be the case if W. Beth  $(\mathcal{L}_1, \mathcal{L}_2)$  holds), then using  $\varphi(x, y)$  we easily distinguish between  $[M^*, M_0]$  and  $[M^*, M_1]$ . Now expanded by the function it defined.

So one is a model of  $\psi_3$  the other not. So W. Beth  $(\mathcal{L}_1, \mathcal{L}_2)$  fail as required.

*2.7 Conclusion.* If

- (a)  $L_{\sigma, \omega} \leq \mathcal{L}_1 \leq \mathcal{L}_2 \leq \mathcal{L}_3$
- (b)  $\psi \in \mathcal{L}_1[\tau]$  has a unique model  $M$  up to isomorphism,  $|\tau| < \sigma$ ,  $M$  is rigid,  $\|M\| + |\tau| \leq \kappa$  and for some  $a \neq b$  from  $M$ ,  $(M, a) \equiv_{\mathcal{L}_3} (M, b)$
- (c)  $PPP(\mathcal{L}_2, \mathcal{L}_3)$

then W. Beth  $(\mathcal{L}_1, \mathcal{L}_2)$  fail.

*Proof.* By 2.5.

- 2.8 Theorem.** 1) If  $1 < \mu \leq \theta^\kappa = \theta \geq \aleph_0$ ,  $\kappa = cf(\kappa) > \aleph_0$  then  $Pr_{L_{\theta^+, \omega}, L_{\infty, \kappa}}^c(\mu, \theta, \theta^+)$  (hence  $Pr_{L_{\theta^+, \omega}, L_{\infty, \kappa}}^b(\mu, \theta, \theta^+)$ ).
- 2) If  $\theta \geq \kappa = cf(\kappa) > \aleph_0$  then for some  $\mu$ ,  $\theta \leq \mu \leq \theta^\kappa$ ,  $Pr_{L_{\theta^+, \omega}, L_{\infty, \kappa}}^b(\mu, \theta, \theta^+)$ .
- 3) Really  $Pr_{L_{\theta^+, \omega}, L_{\kappa^+, \omega}}^x(\mu, \theta, \aleph_0)$  hold for  $x = a, b, c, d$  provided that  $[x = b, d \models \mu > 1]$  (with little effort, but this gives little more than the previous parts).

*Proof.* Essentially from [Sh 189].

1) By [Sh 189, Fact 3.10,p.46] there is a smooth ( $\kappa$ -system) $\mathfrak{A}$ ,  $\|\mathfrak{A}\| = \theta^\kappa = \theta$ , with  $E(\mathfrak{A}) = \mu$  every  $h_{i,j}$  is onto  $G_i(\kappa = cf(\kappa) > \aleph_0$  is understood).

Now look at the proof of [Sh 189, Fact 3.11,p.47], it proves all we want.

We define models  $M_{\mathbf{a}}$  for  $\mathbf{a} \in Gr(\mathfrak{A})$ ; note  $|\text{vocabulary}(M_{\mathbf{a}})| \leq \mu$ .

By [Sh 189, 3.12,p.47]

$$M_{\mathbf{a}} \cong M_{\mathbf{b}} \text{ iff } \mathbf{a} - \mathbf{b} \in \text{Fact}(\mathfrak{A}).$$

By [Sh 189, 3.13,p.48] any two  $M_a, M_b$  are  $L_{\infty, \kappa}$ -equivalent. Let  $\psi$  be the sentence expressing  $(*)$  of [Sh 189, 49<sup>5</sup>]. By [Sh 189, 44<sup>7</sup> - 44<sup>13</sup>]  $\{M_{\mathbf{a}} : \mathbf{a} \in Gr(\mathfrak{A})\}$  is the class of models of  $\psi$  up to isomorphism. As

$$E(\mathfrak{A}) = Gr(\mathfrak{A})/\text{Fact}(\mathfrak{A})$$

we finish.

- 2) Like above using [Sh 189, 3.8] instead 3.15.
- 3) Not used, and is easy, so we left it to the reader.

**2.9 Definition.** For a model  $M$ .

- 1) For logic  $\mathcal{L}$   
 $\text{no}_{\mathcal{L}}(M) = \{N / \cong : N \cong_{\mathcal{L}} M, \|N\| = \|M\|\}$ .
- 2) When  $\mathcal{L} = L_{\infty, \|M\|}$  we omit it.

**2.10 Theorem.** 1) If  $\mu$  is a weakly compact cardinal  $\lambda \leq \mu$  or  $\lambda = 2^\mu$  then  $Pr_{L_{\mu^+, \mu}, L_{\infty, \mu}}^a(\lambda, \mu, \aleph_0)$ .

2) If  $\mu$  is singular strong limit cardinal,  $\lambda < \mu$  or  $\lambda = 2^\mu$  then 1)'s conclusion holds.

*Proof.* 1) By [Sh 133] there is a model  $M$ ,  $\|M\| = \mu \geq |\text{vocabulary}(M)|$  and  $\text{no}(M) = \lambda$  (see Definition 2.9) (decreasing the vocabulary is easy, see [Sh 189]).

2) Use [Sh 228].



**2.11 Lemma.** 1) Suppose  $V = L$  and  $\mu$  is regular uncountable not weakly compact then  $Pr_{L_{\infty, \mu}, L_{\infty, \mu}}^b(\leq \mu, \mu, \mu^+)$  fail (hence by monotonicity  $Pr_{L_{\kappa^+, \mu}, L_{\infty, \mu}}^x(\leq \mu, \mu, \mu^+)$ ).  
 2) If  $\mathcal{L}_1 \leq \mathcal{L}_2 \leq \mathcal{L}_3$  and

(\*) there is no model  $M$ ,  $\|M\| + |\text{vocabulary}(M)| = \theta = \|M\|$ ,  $1 < \text{no}_{\mathcal{L}_2}(M) \leq \mu$

then  $Pr_{\mathcal{L}_1, \mathcal{L}_3}^x(\leq \mu, \theta, < \infty)$  fail for  $x = a, b, c, d$ .

*Remark.* The assumption  $V = L$  is necessary in 2.11, see 2.12.

*Proof.* 1) Follows from (2) as (\*) of part (2) of this lemma holds (for  $\lambda = \aleph_1$  by Palyutin, for  $\lambda \geq \aleph_1$ , by [Sh 129]).

2) By 2.2 without loss of generality  $x = b$ , and let  $\psi$  exemplify  $Pr_{\mathcal{L}_1, \mathcal{L}_2}^b(\leq \mu, \mu, < \infty)$  and we shall eventually get a contradiction.

Let  $M_0, M_1$  be as in (iv)<sup>b</sup> of Definition 2.1. So in  $K = \{M : \|M\| = \mu, M \equiv_{L_{\infty, \mu}} M_0\}$  there are at least two non-isomorphic models. By (\*), in  $K$  there are at least  $\mu^+$  non-isomorphic models, but as  $\psi \in \mathcal{L}_1 \leq \mathcal{L}_2 \leq \mathcal{L}_3$ , all of them are models of  $\psi$ , so (ii) of Definition 2.1 (applied to  $\psi$ ) is contradicted.

**2.12 Fact:** In some generic extension of  $V$ :

(i)  $V \models \text{G.C.H.}$

(ii) for some  $\psi \in \mathcal{L}_{\omega_2, \omega}$ , all models  $M$  of  $\psi$  are  $\mathcal{L}_{\infty, \omega_1}$ -equivalent, and  $\text{no}_{\mathcal{L}_{\infty, \omega_1}}(M) = \aleph_0$ .

*Proof.* By [Sh 125]. (Let  $G$  be a strongly  $\aleph_1$ -free abelian group of cardinality  $\aleph_1$ . Let  $H = G \times \mathbb{Z}$ ,  $h$  the natural projection from  $H$  onto  $G$ . Considering  $H, G, \mathbb{Z}$  as abelian groups, let  $M$  be  $[H, G, \mathbb{Z}]$  enriched by  $h$  and individual constant for every  $c \in G \cup \mathbb{Z}$ ). Now as  $G$  is strongly  $\aleph_1$ -free, if  $h' : H' \rightarrow G$  is a homomorphism onto  $G$ ,  $\text{Ker } h = \mathbb{Z}$  then  $[H', G, \mathbb{Z}; h] \equiv_{L_{\infty, \omega_1}} M$ . Easily (if you understand the definitions)  $\text{no}(M) = |\text{Ext}(G, \mathbb{Z})|$ . But by [Sh 125],  $|\text{Ext}(G, \mathbb{Z})|$  can be  $\aleph_0$ .

**2.13 Conclusion.** 1) If  $\kappa$  is regular,  $> \aleph_0$  then  $\text{W.Beth}(L_{(2^\kappa)^+, \omega}, L_{\infty, \kappa})$  fail.

2) If  $\kappa$  is weakly compact  $> \aleph_0$  or  $\kappa$  strong limit,  $\aleph_0 < \text{cf}(\kappa) < \kappa$  then  $\text{W.Beth}(L_{\kappa^+, \kappa}, L_{\infty, \kappa})$  fail.

3) If  $\theta \geq \kappa = \text{cf} \kappa > \aleph_0$  then  $\text{Beth}(L_{\theta^+, \omega}, L_{\infty, \kappa})$  fail.

*Proof.* 1) Use 2.5 for  $\mathcal{L}_1 = L_{(2^\kappa)^+, \omega}$ ,  $\mathcal{L}_2 = \mathcal{L}_3 = L_{\infty, \kappa}$ ;  $\mu = 2^\kappa = \theta$ ,  $\sigma = \mu^+$  (and  $\kappa$  there is  $2^\kappa$  here) now we have to verify the hypothesis:  $Pr_{\mathcal{L}_1, \mathcal{L}_3}^b(\mu, \theta, \sigma)$  by 2.8(1);  $PPP(\mathcal{L}_2, \mathcal{L}_3)$  is well known. (I think it is due to Malitz — see [Ma]).

2) Like (1) but use 2.10 instead 2.8(1).

3) Use 2.3(1) and 2.8(2).

*Remark.* 1) So by 2.11 in 2.8 we cannot replace  $\theta^\kappa = \theta$  by  $\theta \geq \kappa$ . Can we replace it by  $\theta = \kappa^{+\alpha}$ ? Note, that the proof of 2.11, use only the following consequences of  $V = L$  on  $\mu$

(a) $_\mu$  every stationary  $S \subseteq \mu$  has a stationary subset  $S_1^*$  which does not reflect.

Moreover,  $S_1^*$  satisfies a square principle:

(\*) $_{S_1^*}$  there is  $\langle C_\delta : \delta < \mu, \delta \text{ limit} \rangle$ ,  $C_\delta$  is a club of  $\delta$  disjoint to  $S_1^*$ ,  $\alpha \in C_\delta \& \alpha = \sup(C_\delta \cap \alpha) \Rightarrow C_\alpha = C_\delta \cap \alpha$

(b) $_\mu$  for every stationary  $S \subseteq \mu$  the weak diamond is satisfied (see Devlin Shelah [\DSh:65 ], [\Shb , Ch.XIV, §1].

Now those demands are not hard, e.g. define

(a) $'_\mu$  there is a closed unbounded subset  $C$  of  $\theta$  and a function  $h : C \rightarrow \theta$ ,  $h(\alpha) < \alpha$  such that  $\forall \alpha < \theta [h^{-1}(\{\alpha\})$  does not reflect and it satisfies (\*)].

Now (a) $'_\mu \Rightarrow$  (a) $_\mu$ , (a) $'_\mu$  holds in  $L$ , and if  $V \models$  “(a) $'_\mu$ ” then (a) $'_\mu$  holds in any extension of  $V$  (in which  $\mu$  is still a regular cardinal).

\* \* \*

Now we continue [Sh 199, §3].

**2.14 Definition.** Let  $\mathcal{L}_1 \subseteq \mathcal{L}_2$  be logics.

- (i) We say that the pair of logics  $\mathcal{L}_1, \mathcal{L}_2$  has the Local Homogeneity Property, if for every  $\tau$ -structure  $M$  and  $c_1, c_2 \in M$  such that  $\langle M, c_1 \rangle \equiv_{\mathcal{L}_2} \langle M, c_2 \rangle$  and every  $\varphi \in Th_{\mathcal{L}_1}(\langle M, c_1, c_2 \rangle)$  there is model  $\langle N, c_1^N, c_2^N \rangle \models \varphi$  and a  $\tau$ -automorphism  $g$  of  $N$  such that  $g(c_1^N) = c_2^N$ . If  $\mathcal{L}_1 = \mathcal{L}_2$  we just say that  $\mathcal{L}_1$  has the Local Homogeneity Property
- (ii) We say that  $\mathcal{L}$  has the Local Automorphism Property, if for every  $\tau$ -structure  $M$  and infinite subset  $P \subseteq M$ , every sentence  $\varphi$  of the theory  $Th_{\mathcal{L}}(\langle M, P \rangle)$  has a model  $\langle N, P' \rangle$  which has an automorphism  $g$  of  $N$  such that  $g \upharpoonright P' \neq Id$ .

We now define a Local Automorphism Property for pairs of logics.

**2.15 Definition.** 1) We say that the pair of logics  $\mathcal{L}_1, \mathcal{L}_2$  has the Local Automorphism Property, if for every  $\tau$ -structure  $M$ , every infinite subset  $P \subset M$ , and for every  $a, b \in P$ ,  $a \neq b$  such that  $\langle M, a \rangle \equiv_{\mathcal{L}_2} \langle M, b \rangle$ , every sentence  $\varphi$  of the theory  $Th_{\mathcal{L}_1}(\langle M, P \rangle)$  has a model  $\langle N, P' \rangle$  which has an automorphism  $g$  of  $N$  such that  $g \upharpoonright P' \neq Id$ .

2) We define similarly when  $(\mathcal{L}_1, \mathcal{L}_2)$  has the Local Homogeneity Property.

Note that we do not require in 2.14(i) that the automorphism interchanges  $a$  and  $b$ .

**2.16 Theorem.** Let  $\mathcal{L}_i$ ,  $i = 1, 2, 3$  be three logics such that  $\mathcal{L}_1 \leq \mathcal{L}_2 \leq \mathcal{L}_3$  and that  $INT(\mathcal{L}_1, \mathcal{L}_2)$  and  $PPP(\mathcal{L}_2, \mathcal{L}_3)$  hold. Then the pair of logics  $(\mathcal{L}_1, \mathcal{L}_3)$  has the Local Homogeneity Property.

*Proof.* Let  $M$  and  $c_1, c_2 \in M$  be as in the hypothesis of the Local Homogeneity Property (see Definition 2.14(1)). Let  $M', c'_1, c'_2$  be a disjoint copy. Put  $N = [M, M']$ . Put  $T = Th_{\mathcal{L}_2}(\langle N, c_1, c_2, c'_1 \rangle) = Th_{\mathcal{L}_2}(\langle N, c_1, c_2, c'_2 \rangle)$ . The equality holds because of  $PPP(\mathcal{L}_2, \mathcal{L}_3)$ . Let  $c_1, c_2$  be constant symbols with interpretations  $c_1, c_2$  and  $c$  be a constant symbol with interpretation  $c'_1$  or  $c'_2$  respectively. Let  $F_1, F_2$  be two new function symbols. Let  $\psi_i$ , ( $i = 1, 2$ ) be the sentence which says that  $F_i$  is a  $\tau$ -isomorphism (modulo name changing) mapping the first sort into the second sort which maps  $c_i$  into  $c$ .

Clearly,  $T \cup \{\psi_i\}$  has a model for each  $i = 1, 2$ . Let  $\varphi \in T \cap \mathcal{L}_1[\tau]$ . If  $\{\varphi, \psi_1, \psi_2\}$  has a model  $[M_1, M'_1, F_1, F_2]$  we get the required automorphism in  $M_1$  from the composition of  $F_1$  and  $F_2^{-1}$ . So assume that  $\{\varphi, \psi_1, \psi_2\}$  has no model. We now apply  $INT(\mathcal{L}_1, \mathcal{L}_2)$  and find  $\theta \in \mathcal{L}_2[\tau]$  such that  $\psi_1 \rightarrow \varphi \wedge \theta$  and  $\varphi \wedge \theta \rightarrow \neg\psi_2$  are both valid. But  $\varphi \wedge \theta \in T$  and  $T$  has models which allow expansions satisfying  $\psi_1$  and also models which allow expansions satisfying  $\psi_2$ , a contradiction.

**2.17 Theorem.** Suppose

- (a)  $\mathcal{L}_1 \leq \mathcal{L}_2 \leq \mathcal{L}_3$
- (b)  $PPP(\mathcal{L}_2, \mathcal{L}_3)$
- (c) If  $\psi \in \mathcal{L}_2$  ( $\tau \cup \{P, Q\}$ ) ( $\tau$ -vocabulary,  $P, Q$  predicates)

and: for every  $\tau$ -model  $M$

$$|\{Q : \text{for some } P (M, Q, P) \models \psi\}| \leq 1$$

then for some  $\varphi(x) \in \mathcal{L}_1(\tau)$  for every  $\tau$ -model  $M$

$$(M, Q, P) \models \varphi \models Q = \{a : M \models \varphi[a]\}$$

*Then  $(\mathcal{L}_1, \mathcal{L}_3)$  has the weak Local Automorphism Property (which means, in 2.15(1) we add to the hypothesis  $|P^M| > h(|\tau|)$ ,  $h$  a function depending on  $\mathcal{L}$ ).*

Of course,

*2.18 Observation.* If the pair  $(\mathcal{L}_1, \mathcal{L}_2)$  has the Local Homogeneity Property then this pair has the Local Automorphism Property.

§3  $\Delta$ -CLOSURE DOES NOT HELP BETH

Our main Theorem is 3.5, but most of the work is done in 3.13, and the interest is exposed in the conclusions 3.6 (specific logics), 3.7 (counterexamples in abstract model theory).

Essentially the theorem says that  $\Delta(\mathcal{L}_{\infty,\omega})$  is far from having Beth property: even for implicit definitions in quite weak logics (like  $L(\exists^{\geq \aleph_1})$ ,  $L_{\omega_2,\omega}$ ).

The proof uses the idea of Morley omitting type theorem (in Stage I of the proof of 3.13), Hutchinson's idea of using a model with large cofinality so that it has many  $\mathcal{L}_{\kappa,\omega}$ -elementary submodels with cofinality  $\aleph_0$  and with cofinality  $\aleph_1$ , and the proof of not Beth( $\mathcal{L}$ ) (see the exposition [Ma]).

However, the following theorem isolates a sufficient condition for the failure of the Beth (weak Beth) Property for  $\Delta$ -logics.

Recall:

**3.1 Definition.** For a logic  $\mathcal{L}$ , let  $0(\mathcal{L})$  be the minimal cardinal  $\lambda \geq \aleph_0$  such that for every vocabulary  $\tau$  and  $\psi \in \mathcal{L}[\tau]$  for some  $\tau' \subseteq \tau$  of cardinality  $< \lambda$ : if  $M_1, M_2$  are  $\tau$  models and  $M_1 \upharpoonright \tau' = M_2 \upharpoonright \tau'$  then  $M_1 \models \psi \Leftrightarrow M_2 \models \psi$ .

**3.2 Definition.** Let  $\mathcal{L}$  be a logic with dependence number  $0(\mathcal{L}) \leq \mu$ . Let  $\sigma(P) = \sigma_1(P) \vee \sigma_2(P)$  be a  $\mathcal{L}(\tau \cup \{P\})$ -formula and  $\sigma_1(P), \sigma_2(P)$  are contradictory.

1)  $M$  is a  $(\mu, \kappa)$ -counter example for  $\sigma$  (strictly speaking for  $\langle \sigma_1(P), \sigma_2(P), P \rangle$ ) if  $M$  has vocabulary  $\tau$ ,  $|\tau| < \mu$  and: for every expansion of  $M$  to a  $\tau^*$ -structure  $M^*$ , and  $T \subseteq Th_{\mathcal{L}}(M^*)$ , where  $|T| < \kappa$ , (note  $\tau \subset \tau^*$ ),  $P \notin \tau^*$ , and  $\text{card}(\tau^*) < \mu$ , there are  $\tau^*$ -structures  $N_1, N_2$  such that:

- (i)  $N_\ell \models T$
- (ii)  $N_\ell \models (\exists P) [(N_\ell, P) \models \sigma_\ell(P)]$  for  $\ell = 1, 2$ .

2) If  $\kappa = \aleph_0, \mu = 0(\mathcal{L})$  we say  $M$  is an  $\mathcal{L}$ -counterexample for  $\sigma$ .

*3.3 Remark.* We can use for  $\sigma_\ell(P), \sigma^*(P) \wedge \varphi(P), \sigma^*(P) \wedge \neg\varphi(P)$ .

**3.4 Fact:** Let  $\mathcal{L}$  be a logic with dependence number  $0(\mathcal{L}) \leq \mu$ . Let  $\sigma(P)$  be a  $\mathcal{L}(\tau \cup \{P\})$ -formula which is an implicit (weak implicit<sup>1</sup>) definition of  $P$ .

1) Assume that  $M$  is an  $\mathcal{L}$ -counter example for  $\sigma$ . Then  $\Delta(\mathcal{L})$  does not have the

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<sup>1</sup>i.e. for every  $\tau$ -model there is a unique  $P$

(Weak) Beth Property.

2) If  $M$  is a  $(\mu, \infty)$ -counter example for  $\sigma$  then  $\Delta(\mathcal{L})$  fails the FWROB (see [Ma]).

*Proof.* 1) Let  $\sigma(P)$  be a  $\mathcal{L}(\tau \cup \{P\})$ -formula which is an implicit (weak implicit) definition of  $P$ . Assume for contradiction that there is an explicit definition for  $P$  given by a formula  $\theta(x) \in \Delta(\mathcal{L})$ . Since  $\Delta(\mathcal{L})$  has the same dependence number as  $\mathcal{L}$ , there are a vocabulary  $\tau^\#$  with  $\tau \subseteq \tau^\#$  and  $\text{card}(\tau^\#) < \mu$  and  $\theta_1(x), \theta_2(x) \in \mathcal{L}(\tau^\#)$  which forms the  $\Delta$ -definition of  $\theta$ . This means that for every  $\tau$ -model  $M$  and  $a \in M$  there is a unique  $\ell \in \{1, 2\}$  such that for some expansion  $M^\#$  of  $M$  to a  $\tau^\#$ -model  $M^\# \models \theta_\ell[a]$ . Let for simplicity  $\tau^\# - \tau = \{R_i : i < \alpha\}$ , and let  $R'_i$  a predicate with  $(n(R_i) + 1)$ -place. Now let  $M$  a  $\mathcal{L}$ -counterexample to  $\sigma(P)$ , for every  $a \in M$  let  $\ell(a) \in \{1, 2\}$ ,  $R_i^a \subseteq {}^{n(R_i)}M$  for  $i < \alpha$  be such that:

$$(M, R_i^a)_{i < \alpha} \models \theta_{\ell(a)}[a].$$

Define  $R'_i = \{ \langle a \rangle \hat{\ } \bar{b} : \bar{b} \in R_i^a \text{ where } a \in M \}$ ,  $M^* =: (M, R'_i)_{i < \alpha}$  define  $\theta'_\ell(x)$  accordingly (substitute  $R'_i(x, y_1, \dots, y_n)$  instead  $R_i(y_1, \dots, y_n)$ ). Note: for  $a \in M^* : M^* \models \theta'_\ell[a]$  iff  $M^* \models \theta_{3-\ell}[a]$ . Let  $T = \{ \forall x [\theta'_1(x) \equiv \neg \theta'_2(x)] \} \{ \varphi : M^* \models \varphi, \varphi \text{ is } F \text{ Sub}_{\theta'_\ell(x)}^{P(x)} \sigma_\ell(P) \text{ for } \ell = 1, 2 \}$ . So there are  $N_1, N_2$  as required in Definition 3.2 so there are for  $\ell = 1, 2$ ,  $P^\ell \subseteq N_\ell$ ,  $(N_\ell, P^\ell) \models \sigma_\ell(P)$ . By the choice of  $(\theta_1(x), \theta_2(x))$  and of  $M^*$ , for  $\ell = 1, 2$  we have:

$$P^\ell = \{ a \in N_\ell : N_\ell \models \theta_1[a] \}.$$

So  $N_\ell \models F \text{ Sub}_{\theta'_\ell(x)}^{P(x)} \sigma_\ell(P)$  hence  $M^* \models F \text{ Sub}_{\theta'_\ell(x)}^{P(x)} \sigma_\ell(P)$ . Let  $P^* = \{ a \in M^* : M \models \theta_1[a] \}$ , then  $M^* \models \sigma_\ell(P^*)$  for  $\ell = 1, 2$ ; but  $\sigma_1(P), \sigma_2(P)$  are contradictory; contradiction.

2) Same proof with  $T = Th_{\mathcal{L}}(M^*)$ .

**3.5 Theorem.** *Beth( $\mathcal{L}, \Delta(L_{\infty, \omega})$ ) and, for every  $\mu$ , FWROB( $\mathcal{L}, \Delta(L_{\mu, \omega})$ ) fail if for some distinct regular cardinals  $\kappa_1 \neq \kappa_2$  and  $\theta_\ell \in \mathcal{L}(\tau_i)$  where  $\tau_1 \cap \tau_2 = \tau_0 = \{ \langle \rangle \}$ , we have, for  $\ell = 1, 2$ :*

- (a)  $K_\ell^d =: \{ M \upharpoonright \tau_0 : M \models \theta_\ell \}$  are disjoint
- (b) for arbitrarily large  $\mu$ , if  $(|M|, <^\mu)$  is a linear order of cardinality  $\mu$  and cofinality  $\kappa_\ell$  then  $M \in K_\ell$ .

*Proof.* It follows from the main lemma 3.13 proved below and 3.4. So we first draw conclusion, and then proceed to preparation for 3.13.

- 3.6 Conclusion.** 1) If  $\lambda > \aleph_0$  is regular,  $\mu$  any cardinal then  $\text{Beth}(L_{\omega,\omega}(\exists^{\geq\lambda}), \Delta(L_{\infty,\omega}))$  and  $\text{FWROB}(L_{\omega,\omega}(\exists^{\geq\lambda}), \Delta(L_{\mu,\omega}))$  fail.
- 2) In particular this holds for the logic with the quantifier: there are uncountably many.
- 3)  $\text{Beth}(L_{\omega_2,\omega}, \Delta(L_{\infty,\omega}))$ ,  $\text{FWROB}(L_{\omega_2,\omega}, \Delta(L_{\mu,\omega}))$  fail.
- 4) For  $\mu > \aleph_1$   $\text{Beth}(\Delta(L_{\infty,\omega}))$  fail and  $\text{Beth}(\Delta(L_{\mu,\omega}))$ ,  $\text{FWROB}(\Delta(L_{\mu,\omega}))$  fail.

**3.7 Corollary.** *Let  $\mathcal{L}_1, \mathcal{L}_2$  be two logics. Then*

- (i)  $\Delta\text{-Int}(\mathcal{L}_1, \mathcal{L}_2)$  (see definition below) does not imply  $\text{BETH}(\mathcal{L}_1, \mathcal{L}_2)$
- (ii)  $\Delta\text{-Int}(\mathcal{L}_1, \mathcal{L}_2)$  does not imply  $\text{WFROB}(\mathcal{L}_1, \mathcal{L}_2)$ .

The subsequent definitions and lemmas lead to a proof of 3.5.

**3.8 Definition.**  $\Delta\text{-Int}(\mathcal{L}_1, \mathcal{L}_2)$  means: if  $\psi_\ell \in \mathcal{L}_1[\tau_\ell]$  for  $\ell = 1, 2$ ,  $\tau = \tau_1 \cap \tau_2$  and the class of  $\tau$ -models is the disjoint union of

$$K_1 = \{M \upharpoonright \tau : M \text{ a } \tau_1\text{-model satisfying } \psi_1\} \text{ and}$$

$$K_2 = \{M \upharpoonright \tau : M \text{ a } \tau_2\text{-model satisfying } \psi_2\}$$

then  $K_1$  is the class of  $\tau$ -models of  $\psi^*$  for some  $\psi^* \in \mathcal{L}_2[\tau]$ .

Explanation: What is the point of the following game? We, on the one hand, want to build a type of indiscernibles to be able to control the cofinality. On the other hand, if the type say it is bounded, we are lost. If the cofinality is weakly compact, we can use partition theorems, but maybe the class of weakly compact is bounded. But restricting ourselves to rapid sequences solve the dilemma — it ensures unboundedness, and gives one type.

**3.9 Definition.** Suppose  $M$  is a model,  $A$  a subset of  $|M|$ ,  $< a$  two place relation which linearly orders  $A$  with no last element, and  $\Phi$  a set of formulas  $\varphi(\bar{x}, \bar{d})$  in the vocabulary of  $M$  with parameters from  $|M|$ .

1) We say  $\langle a_i : i < \alpha \rangle$  is rapid for  $(A, <)$  over  $\Phi$  inside  $M$  if in the following game player I has no winning strategy:

a play last  $\alpha$  moves:

in the  $\beta$ -th move player I choose  $b_i \in A$  and player II choose  $c_i \in A$ , such that  $b_i < c_i$

in the end player II wins if for every  $\varphi(x_1, x_2, \dots, x_n, \bar{d}) \in \Phi$ , and  $i_1 < i_2 < \dots < i_n < \alpha$  we have:

$$M \models \varphi[a_{i_1}, \dots, a_{i_n}, \bar{d}] \equiv \varphi[c_{i_1}, \dots, c_{i_n}, \bar{d}].$$

- 2) If  $B \subseteq M$ ,  $\Theta$  a set of formulas with vocabulary included in the vocabulary of  $M$ , we write  $(B, \Delta)$  instead  $\Phi_{(B, \Delta)}^d =: \{\varphi(\bar{x}, \bar{d}) : \bar{d} \subseteq B \text{ and } \varphi(\bar{x}, \bar{y}) \in \Theta\}$ .
- 3) We write  $(\Psi, n)$  instead  $\Phi_{(\Psi, n)}^d$  where  $\Phi_{(\Psi, n)}^d =: \{\varphi(x_1, \dots, x_n, \bar{d}) : \varphi(x_1, \dots, x_n, \bar{d}) \in \Psi\}$ .
- 4) We write  $(B, \Theta, n)$  instead  $\Phi_{(\Phi_{(B, \Theta)}, n)}$ .
- 5) If  $\Theta$  is the set of first order formulas in the vocabulary of  $M$  we omit it.
- 6) Writing “ $\leq n$ ” instead “ $n$ ” has the obvious meaning.
- 7) Instead “ $A$ ”, “ $<$ ”, “ $B$ ” we may write a formula which defines them. If the identity of “ $<$ ” is obvious — we omit it.

**3.10 Claim.** 1) For any model  $M$ ,  $A, B \subseteq M$ ,  $<$  (two-place relation) such that  $(A, <)$  is linear with no last element,  $\Phi$  are as above and  $a_i \in A$  for  $i < \alpha$ , we have:

$\langle a_i : i < \alpha \rangle$  is rapid for  $(A, <)$  over  $(\Phi, \leq, 0)$  inside  $M$ .

- 2) If  $\langle a_i : i < \alpha \rangle$  is rapid for  $(A^*, <)$  over  $\Phi^*$  inside  $M$ ,  $\Phi \subseteq \Phi^*$ ,  $A \subseteq M$ ,  $\langle i(\zeta) : \zeta < \xi \rangle$  is a strictly increasing sequence of ordinals  $< \alpha$  then  $\langle a_{i(\zeta)} : \zeta < \xi \rangle$  is rapid for  $(A, <)$  over  $\Phi$  inside  $M$ .
- 3) If  $\langle a_i : i < \alpha \rangle$  is rapid for  $(A, <)$  over  $(\Phi^*, n)$  inside  $M$ ,  $n = 2$ ,  $[x_1 < x_0] \in \Phi$  then  $\langle a_i : i < \alpha \rangle$  is strictly increasing and  $|\alpha| < cf(A, <)$ .

*Proof.* Easy.

**3.11 Claim.** If  $\langle a_i : i < \alpha \rangle$  is rapid for  $(A, <)$  over  $\Theta$  inside  $M$ ,  $\Theta \subseteq \Psi$ ,  $cf(A, <)$  is bigger than  $2^{|\Psi| + |\alpha|}$  then there are  $b_i (i < \alpha)$  such that:

- (a)  $\langle b_i : i < \alpha \rangle$  is rapid for  $(A, <)$  over  $\Psi$  inside  $M$
- (b) for  $\varphi(x_1, \dots, x_n, \bar{d}) \in \Theta$ ,  $i_1 < \dots < i_n < \alpha$  we have  $M \models \varphi[b_{i_1}, \dots, b_{i_n}, \bar{d}] \equiv \varphi[a_{i_1}, \dots, a_{i_n}, \bar{d}]$ .

*Proof.* The point is that any family of less than  $cf(A, <)$  strategies for player I can be combined to one strategy.

*3.12 Remark.* In 3.13 (and 3.6) if we assume there is a class of measurable, we can simplify the proof and get  $N \upharpoonright \tau \prec M$ . We can waive the notion of “rapid” just let  $D_\eta$  be a normal ultrafilter on  $\lambda_\eta$  and  $H(\eta)$  is such that  $\{i : \eta^\wedge < i\}$  appear  $H(\eta) \in D_\eta$ .



**3.13 Main Lemma.** : *Suppose*

- (a)  $\psi \in L_{\mu+, \omega}[\tau]$ ,  $|\tau| \leq \mu$  (where  $\tau$  is a vocabulary);
- (b)  $M^* \models \psi$ , ( $\tau =$  vocabulary of  $\mu$ ),  $\psi \models Th_{L_{\omega, \omega}}(M^*)$
- (c)  $T$  is a non-empty set of finite sequences of ordinals, closed under initial segments,  $\langle \rangle \in T$ , and for every  $\eta \in T$  for some cardinal  $\lambda_\eta > \mu$ :

$$\eta^\wedge \langle i \rangle \in T \Leftrightarrow i < \lambda_\eta$$

- (d)  $T = P^{M^*}$ ,  $\langle^M = \{\eta^\wedge \langle i \rangle, \eta^\wedge \langle j \rangle\} : \eta \in T, i < j < \lambda_\eta\}$ ,  $F_\ell^M(\eta) = \eta \upharpoonright \ell$ ,  $P_n^{M^*} = \{\eta \in T : \ell g(\eta) = n\}$ ,  $R$  a coding function on  $\{\eta^\wedge \langle i \rangle : i < \lambda_\eta\}$
- (e)  $\eta \neq \nu \Rightarrow \lambda_\eta \neq \lambda_\nu$  for  $\eta, \nu \in T$ ;  $\lambda_{\eta \upharpoonright k} < \lambda_\eta$  for  $k < \ell g(\eta)$ ,  $\eta \in T$  and for simplicity  $[\eta, \nu \in T, \ell g(\eta) < \ell g(\nu) \models \lambda_\eta < \lambda_\nu]$
- (f) for  $\eta \in T$ ,  $\lambda_\eta$  is regular and  $\geq \beth_{(2^\mu)^+}(\mu_\eta)$  where  $\mu_\eta =: \mu + \sum\{\lambda_\nu : \lambda_\nu < \lambda_\eta\}$
- (g)  $\kappa_1 \neq \kappa_2$  are regular cardinals  $< \underset{\eta \in T}{\text{Min}} \lambda_\eta$
- (h)  $\tau_0 \subseteq \tau$ , the relation belongs to  $\tau_0$ ,  $K_0$  a class of  $\tau_0$ -models, (closed under isomorphism), such that for every  $\eta \in T : (M^* \upharpoonright \tau_0) \upharpoonright \{\eta^\wedge \langle i \rangle : i < \lambda_\eta\}$  belongs to  $K_0$
- (i) if  $M \in K_0$  then  $\langle^M$  linearly ordered  $|M|$
- (j) if  $M \in K_0$ ,  $\ell \in \{1, 2\}$ ,  $\|M\| = \mu$  and  $cf(|M|, \langle^M) = \kappa_\ell$  then for some  $Q$ ,  $(M, Q) \in K_\ell$
- (k)  $K_\ell$  is a class of  $(\tau_0 \cup \{Q\})$ -models closed under isomorphism and  $K'_\ell = \{N \upharpoonright \tau_0 : N \in K_\ell\}$  and  $K'_0, K'_1$  are disjoint

then there is a  $\tau$ -model  $N$  of  $\psi$  and  $Q \subseteq \bigcup_n P_n^N$  such that:

- (1)  $P_0^N \subseteq Q$  (necessarily  $|P_0^N| = 1$ )
- (2) for every  $x \in P_n^N$  letting  $N_x = (N \upharpoonright \tau_0) \upharpoonright \{y \in P_{n+1}^N : F_n(y) = x\}$ , the following are equivalent:
  - (i)  $cf(N_x, \langle) = \kappa_1$
  - (ii)  $cf(N_x, \langle) \neq \kappa_2$
  - (iii)  $(N_x, Q \cap N_x) \in K_1$
  - (iv)  $(N_x, Q \cap N_x) \notin K_2$  (hence  $N_x \notin K_1$ )

*Proof.*

Stage A - Definition: 1) We say  $(M, H)$  is an  $\alpha$ -approximation if:

- ( $\alpha$ )  $M$  is an expansion of  $M^*$  with Skolem functions (for first order formulas); having a name for every subformula of  $\psi$
- ( $\beta$ )  $M$  has vocabulary of cardinality  $\leq \mu$
- ( $\gamma$ )  $H$  has domain  $\subseteq P^M (= T)$  and for every  $\eta \in \text{Dom}(H)$   $H(\eta)$  is a  $<$ -increasing sequence of members of  $B_\eta^* = \{\eta \hat{< } i \hat{>}, i < \lambda_\eta\}$  of length  $\beth_\alpha(\mu_\eta)^+ : \langle H_\eta(i) : i < \beth_\alpha(\mu_\eta)^+ \rangle$
- ( $\delta$ )  $H(\eta)$  is rapid for  $(B_\eta^*, <)$  over  $A_\eta^* =: \cup\{B_\nu^* : \lambda_\nu < \lambda_\eta\}$  inside  $M^*$ .

2) If we omit  $\alpha$  this means for some  $\alpha$ . We call  $(M, H)$  full if  $\text{Dom } H = P^{M^*}$ .

Stage B - Definition: 1) We say for approximations  $(M^\ell, H^\ell)$ , ( $\ell = 1, 2$ ) that  $(M^1, H^1) \leq (M^2, H^2)$  if:

- ( $\alpha$ )  $M^2$  is an expansion of  $M^1$
- ( $\beta$ )  $\text{Dom } H^1 \subseteq \text{Dom } H^2$
- ( $\gamma$ ) for every  $\eta \in \text{Dom } H^1$ , there is an increasing sequence  $\langle i(\zeta) : \zeta < \ell g(H^2(\eta)) \rangle$  of ordinals  $< \ell g(H^1(\eta))$  such that the sequences  $H^2(\eta)$ ,  $\langle H_\eta^1(i(\zeta)) : \zeta < \ell g(H^1(\eta)) \rangle$  realize the same type in  $M^1$  over  $A_\eta^*$ .

2) We say  $(M^1, H^1) \leq_{pr} (M^2, H^2)$  if in addition  $\text{Dom } H^1 = \text{Dom } H^2$ ,  $\ell g(H^1(\eta)) = \ell g(H^2(\eta))$  (both relations defined in this stage are partial order).

Stage C - Definition: 1) We say an approximation  $(M, H)$  is  $(n, m, k)$ -indiscernible if:

for any distinct  $\eta_1, \dots, \eta_m \in P_n^{M^*}$ , and for  $\ell = 1, \dots, m$ ,  $\bar{b}_\ell, \bar{c}_\ell$  are increasing subsequences of  $H(\eta_\ell)$  of length  $k$  then the types  $\bar{b}_1 \hat{< } \dots \hat{< } \bar{b}_n, \bar{c}_1 \hat{< } \dots \hat{< } \bar{c}_m$  realizes over  $\bigcup_{\ell \leq n} P_\ell^{M^*}$  inside  $M^*$  are equal.

2) If  $k = m$  omit it.

Stage D - Fact: For every  $\alpha < \beth_{(2^\mu)^+}(\mu)$  there is an  $\alpha$ -approximation  $(M, H)$ .

*Proof.* Expand  $M^*$  by names for subformulas of  $\psi$  and then add Skolem functions. Lastly use 3.11 to define  $H$ ,  $\text{Dom } H = T$ .

Stage E- Fact: For any approximation  $(M^1, H^1)$ , we can find  $M^2, H^2$  such that:

- ( $\alpha$ )  $(M^2, H^2)$  is an approximation,  $(M^1, H^1) \leq (M^2, H^2)$ .  
 ( $\beta$ ) there is a predicate  $R \in \tau(M^2) - \tau(M^*)$ ,  $R = \{(\eta, a) : a \in H^1(\eta)\}$ .

*Proof.* First find an expansion  $M^3$  of  $M^1$  by suitable  $R$ , so  $|\tau(M^3)| \leq \mu$ . Second find an expansion  $M^2$  of  $M^3$  which has Skolem functions and  $|\tau(M^2)| \leq \mu$ . Lastly we find  $H^2$  : just apply 3.11 for each  $\eta \in \text{Dom } H^1$  and apply 3.11 with  $H^1(\eta)$ ,  $(B_\eta^*, <)$ ,  $\Theta_\eta = \{\varphi : \varphi \text{ an } L_{\omega, \omega}[\tau(M^1)]\text{-formula with parameters from } A_\eta^*\}$ ,  $\Psi_\eta = \{\varphi : \varphi \text{ an } L_{\omega, \omega}[\tau(M^2)]\text{-formula with parameters from } A_\eta^*\}$  here standing for  $\langle a_i : i < \alpha \rangle$ ,  $(A, <)$ ,  $\Theta$ ,  $\Psi$  there. What we get  $(\langle b_i : i < \beth_\alpha(\mu_\eta)^+ \rangle)$  will be called  $H^2(\eta)$ .

Stage F - Claim: If  $(M^1, H^1)$  is an  $\alpha$ -approximation  $\beta + k \times m \leq \alpha$ ,  $n, m, k < \omega$  then there is a  $\beta$ -approximation  $(M^2, H^2)$  which is  $(n, m, k)$ -indiscernible and  $(M^1, H^1) \leq (M^2, H^2)$ .

*Proof.* By polarized partition relation of Erdos Hajnal Rado [EHR]. See representation (in our terminology) [Sh 18], (or [\Sha , AP]) (or Erdos Hajnal Mate Rado [EHRM]).

Stage G: Rest of the proof of Theorem 3.13.

We use the style of [Sh18 , §5] — see [\Sha , VII, §5].

Let  $\chi$  be regular, large enough, such that  $M^* \in H(\chi)$ ,  $<_\chi^*$  a well ordering of  $H(\chi)$ , and let  $\mathfrak{A} = \{i : i \leq \mu\} \cup \tau(M^*)$ .

Let  $\mathfrak{A}^* = (H(\chi), \in, <_\chi^*, M^*, a)_{a \in \mathfrak{A}}$ . There is a model  $\mathfrak{A}$  of  $Th_{\mathcal{L}_{\omega, \omega}}(\mathfrak{A}^*)$  such that  $\mathfrak{A}$  omit every type which  $\mathfrak{A}^*$  omits and  $\{t : \mathfrak{A}^* \models \text{“}t \text{ is an ordinal } < \beth_{(2^\mu)^+}(\mu)\}$  is not well ordered. So there are  $t_n \in \mathfrak{A}$  such that:

$$\begin{aligned} & \models \text{“}t_n \text{ is an ordinal } < \beth_{(2^\mu)^+}(\mu) \\ & \models \text{“}t_{n+1} + (n+1)^2 < t_n \text{”}. \end{aligned}$$

In  $\mathfrak{A}$  we define by induction on  $n, Q_n, (M^n, H^n)$  such that:

- ( $\alpha$ )  $\mathfrak{A} \models \text{“}(M^n, H^n)$  is a  $t_n$ -approximation  
 ( $\beta$ )  $\mathfrak{A} \models \text{“}(M^n, H^n) \leq (M^{n+1}, H^{n+1})$   
 ( $\gamma$ ) If  $n = 2(m^2 + k)$ ,  $k < m$  then  $(M^{n+1}, H^{n+1})$  is  $(m, k)$ -indiscernible and  $(M^{n+1}, H^{n+1})$  relates to  $(M^n, H^n)$  as in Stage  $E$   
 ( $\delta$ )  $R_n \in \tau(M^{n+1}) - \tau(M^n)$ , for  $n = 2m + 1$   
 $R_n = R_{n+1} = \{(\eta, a) : a \in H^n(\eta)\}$ .

For  $n = 0$  use stage D.

For  $n = \ell + 1$ ,  $\ell$  odd use stage E to define  $(M^n, H^n)$ .

For  $n = \ell + 1$ ,  $\ell$  even use stage F to define.

Now let  $\tau_n = \tau(M_n)$ ,  $N_n$  be the Skolem Hull of  $\emptyset$  in  $M^n$  (more exactly  $M^n$  as interpreted in A). So  $\tau(N_n) = \tau_n$ ,  $\tau_n \subseteq \tau_{n+1}$ ,  $|\tau_n| \leq \mu$ ,  $N_n \prec N_{n+1}$  (i.e.  $N_n \prec (N_{n+1} \upharpoonright \tau_n)$ ) and let  $N_\omega = \bigcup_n N_n$ ,  $\tau_\omega = \cup \tau_n$ . So  $N_n \prec N_\omega$ .

We now define by induction on  $n \leq \omega$  model  $N_n^*$  and  $Q_n$  such that:

- (A)  $N_0^* = N_\omega$ ,  $\tau(N_n^*) = \tau_\omega$
- (B)  $N_n^* \prec N_{n+1}^*$ ,  $N_\omega^* = \bigcup_{n < \omega} N_n^*$ ,
- (C) For  $\ell \leq n$ ,  $P_0^{N_n^*} = P_\ell^{N_{n+1}^*}$
- (D)  $N_n^*$  is the Skolem Hull of  $|N_\omega| \cup (\bigcup_{\ell \leq n} P^{N_n^*})$
- (E)  $Q_n \subseteq P_n^{N_n^*}$
- (F)  $Q_0 = P_0^{N_0^*}$
- (G) for every  $\eta \in P_0^{N_n^*}$  (where  $N_\eta$  is defined as in (2) of the conclusion of 3.13):  
 if  $\eta \in Q_n$  then  $cf((N_{n+1}^*)_\eta, <^{N_{n+1}^*}) = \kappa_1$   
 if  $\eta \notin Q_n$  then  $cf((N_n^*)_\eta, <^{N_{n+1}^*}) = \kappa_2$
- (H) for each  $\eta \in P_n^{N_n^*} = P_n^{N_{n+1}^*}$ ,  $((N_n^*)_\eta, Q) \in K_1 \cup K_2$
- (I) for each  $n < \omega$ , every  $L_{\omega, \omega}[\tau_n]$ -type realized in  $N_n^*$  is realized in  $N_0^* = N_\omega$ ,  
 i.e. in some  $N_m$ ,  $m < \omega$ .

The construction is straightforward: in the induction step use the indiscernibility built in [we can add  $\|N_n^*\| = \mu$ ].

*3.14 Remark.* We can get from the proof some additional information which does not seem useful. We can use  $\delta(\mu)$  instead  $\beth_{(2|\tau|)^+}$ , omit every type which  $M^*$  omit. We can have in  $N_{n+1}^*$ , assign arbitrary cofinalities to  $(|N_{n+1}^*|, <^{N_{n+1}^*})$ .

**3.15 Theorem.** *Suppose in (our universe of set theory)  $V$ , for every  $\alpha$  there is a measurable of order  $\alpha$  (see e.g. Gitik [G]). Then in some generic extension  $V'$ :*

- (\*) for every regular  $\mu < \lambda$ : if  $\mathcal{L}$  is a logic,  $L(\exists^{\geq \lambda}) \leq \Delta(\mathcal{L})$  then  $Beth(\mathcal{L}, \Delta(L_{\infty, \mu}))$  fail.

*Proof.* Immediate by Gitik [G], but to clarify we deal with it lengthily. We use the following theorem of Gitik [G]:

( $\oplus$ ) if  $\kappa$  is a measurable of order  $\theta$ ,  $\theta$  a regular cardinal  $< \kappa$  and  $\lambda < \kappa$  then for some forcing notions  $P_{\kappa,\lambda,\theta}, Q_{\kappa,\lambda,\theta} (\in V^{P_{\kappa,\lambda,\theta}})$  the following holds.

$P_{\kappa,\lambda,\theta}$  is  $\lambda$ -pseudo complete (see [Sh:b, Ch.X]) does not collapse cardinals, retain the regularity of  $\kappa$ .

$Q_{\kappa,\lambda,\theta}$  is  $\lambda$ -pseudo complete, does not collapse cardinals, change the cofinality of  $\kappa$  to  $\theta$  and add no new sequences of ordinals of length  $< \theta$ .

We also have (really follows generally, see [Sh 250]) minimal elements  $\emptyset$  and order  $\leq_0$  witnessing to  $\lambda$ -pseudo completeness.

Suppose  $W$  is a set of triples  $(\kappa, \lambda, \theta)$ , of regular cardinals  $\theta < \lambda < \kappa$  such that

$$\bigwedge_{\ell=1,2} (\kappa_\ell, \lambda_\ell, \theta_\ell) \in W \wedge \kappa_1 < \kappa_2 \Rightarrow \kappa_1 < \lambda_2.$$

Let  $W[\kappa'] = \{(\kappa, \lambda, \theta) \in W : \kappa < \kappa'\}$ . We define  $P_W$  as

$$\left\{ \begin{array}{l} \bar{p} : \bar{p} = \langle p_{(\kappa,\lambda,\theta)} : (\kappa, \lambda, \theta) \in W \rangle, \\ p_{(\kappa,\lambda,\theta)} \text{ is a } P_{W[\kappa]} \text{-name of a member of } \\ P_{\kappa,\lambda,\theta} \text{ such that} \\ \{(\kappa, \lambda, \theta) : \not\leq_0 p_{(\kappa,\lambda,\theta)}\} \text{ is finite} \end{array} \right\}$$

with obvious order (both  $\leq$  and  $\leq_0$ ).

Next  $Q_W \in V^{P_W}$  is defined as:

$$\left\{ \begin{array}{l} \bar{q} : \bar{q} = \langle q_{(\kappa,\lambda,\theta)} : (\kappa, \lambda, \theta) \in W \rangle \\ q_{(\kappa,\lambda,\theta)} \in (Q_{(\kappa,\lambda,\theta)})^{V_{W[\kappa]}^P} \text{ and} \\ \{(\kappa, \lambda, \theta) \in W : \not\leq_0 q_{(\kappa,\lambda,\theta)}\} \text{ is finite} \end{array} \right\}$$

order the obvious one ( $\leq$  and  $\leq_0$ ).

Now  $P_W, Q_W$  has the expected properties. We force with the iteration  $\bar{R} = \langle R_i : i < \infty \rangle$  (support as in  $P_W$ ) where for each  $i$  for some  $\mu_i$ ,  $\bar{R} \upharpoonright i \in H(\mu_i)$ ,  $R_i \in \{P_{W_i}, P_{W_i}^*, Q_{W_i}\}$ ,  $2^{\mu_i} < \text{Min}\{\lambda : (\kappa, \lambda, \Theta) \in W_i\}$ . The rest is left to the reader.

## References

- [DSh 65] K. Devlin and S. Shelah, A weak form of the diamond which follows from  $2^{\aleph_0} < 2^{\aleph_1}$ , Israel J. of Math. 29(1978), 239-247.
- [EHR] P. Erdos, A. Hajnal and R. Rado, Partition relations for cardinal numbers, Acta Math. Sci Hung. 16(1965), 193-196.
- [EHMR] P. Erdos, A. Hajnal, A. Mate and R. Rado, Combinatorial set theory: partition relations for cardinals, North Holland Publ. Co., Amsterdam (1984).
- [G] M. Gitik, Changing cofinalities and the non-stationary ideal, Israel J. Math (1986,7).
- [HoSh 109] W. Hodges and S. Shelah, Infinite reduced products, Annals of Math Logic 20(1981), 77-108.
- [HoSh 271] \_\_\_\_\_, There are reasonable nice logics, J. of Symb. Logic.
- [Ma] J.A. Makowsky, Compactness embeddings and definability, Model Theoretic Logics, ed. J. Barwise and S. Feferman, Springer-Verlag group, pp. 645-716.
- [MaSh 62] J.A. Makowsky and S. Shelah, The theorems of Beth and Craig in abstract logic I, Trans. A.M.S. 256(1979), 215-239.
- [MaSh 101] \_\_\_\_\_, The theorems of Beth and Craig in abstract model theory, II, Compact Logics, Proc. of a Workshop, Berlin, July 1977, Archive fur Math. Logik, 21(1981), 13-36.
- [MaSh 116] \_\_\_\_\_, Positive results in abstract model theory; a theory of compact logics, Annals of Pure and Applied Logic, 25(1983), 263-299.
- [MShS 47] J.A. Makowsky, S. Shelah and J. Stavi,  $\Delta$ -logics and generalized quantifiers, Annals of Math. Logic 10(1976), 155-192.
- [MkSh 166] A.H. Mekler and S. Shelah, Stationary logic and its friends, I, Proc. of the 1980/1 Jerusalem Model Theory year, Notre Dame J. of Formal Logic, 26(1985), 129-138.
- [MkSh 187] \_\_\_\_\_, Stationary logic and its friends II, Notre Dame J. of Formal Logic, 27(1986), 39-50.
- [PiSh 130] A. Pillay and S. Shelah, Classification over a predicate I, Notre Dame J. of Formal Logic, 26 (1985), 361-376.

- [RuSh 84] M. Rubin and S. Shelah, On the elementary equivalence of automorphism groups of Boolean algebras, Downward Skolem-Lowenheim theorems and compactness of related quantifiers, *J. of Symb. Logic*, 45(1980), 265-283.
- [Sh-a] S. Shelah, Classification theory and the number of non-isomorphic models, North Holland Publ. Co., 1978, 542 + *XVI*.
- [Sh - b] \_\_\_\_\_, Proper forcing, Springer Lecture Notes, 940(1982), 496 + *XXIX*.
- [Sh 8] \_\_\_\_\_, Two cardinal compactness, *Israel J. Math.* 9(1971), 193-198.
- [Sh 18] \_\_\_\_\_, On models with power-like orderings, *J. of Symb. Logic* 37(1972), 247-267.
- [Sh 43] \_\_\_\_\_, Generalized quantifiers and compact logic, *Trans. of A.M.S.* 204(1975), 342-364.
- [Sh 56] \_\_\_\_\_, Refuting Ehrenfeucht Conjecture on rigid models, *Proc. of the Symp. in memory of A. Robinson, Yale, 1975*, A special volume in the *Israel J. of Math.* 25(1976), 273-286.
- [Sh 72] \_\_\_\_\_, Models with second order properties I, *Boolean Algebras with no undefinable automorphisms*, *Annals of Math. Logic* 14(1978), 57-72.
- [Sh 107] \_\_\_\_\_, Models with second order properties IV, A general method and eliminating diamonds, *Annals. of Math. Logic*, 25(1983), 183-212.
- [Sh 125] \_\_\_\_\_, Consistency of  $Ext(G, \mathbf{Z}) = Q$ , *Israel J. of Math.* [BSF] 39 (1981), 74-82.
- [Sh 129] \_\_\_\_\_, On the number of non-isomorphic models of cardinality  $\lambda$ ,  $L_{\infty, \lambda}$ -equivalent to a fix model, *Notre Dame J. of Formal Logic*, 22(1981), 5-10.
- [Sh 133] \_\_\_\_\_, On the number of non-isomorphic models in  $\lambda$ ,  $L_{\infty, \lambda}$ -equivalent to a fix model when  $\lambda$  is weakly compact, *Notre Dame J. of Formal Logic*, 23(1982), 21-26.
- [Sh 188] \_\_\_\_\_, A pair of non-isomorphic models of power  $\lambda$  for  $\lambda$  singular with  $\lambda^{\aleph_0} = \lambda$ , *Notre Dame J. of Formal Logic*, 25(1984), 97-104.
- [Sh 189] \_\_\_\_\_, On the possible number of  $no(M) =$  the number of non-isomorphic models  $L_{\infty, \lambda}$  equivalent to  $M$  of Power  $\lambda$ , for singular  $\lambda$ , *Notre Dame J. of Formal Logic*, 26(1985), 36-50.
- [ShSn 179] S. Shelah and C. Steinhorn, On the axiomatizability by finitely many schemes, *Notre Dame J. of Formal Logic*, 27(1986), 1-11.
- [ShSn 180] \_\_\_\_\_, The non-axiomatizability of  $L(Q_2^M)$ , in *Notre Dame J. of Formal Logic*,

[Sh 199] -----, Remarks in abstract model theory, Annals of Pure and Applied Logic, 29(1985), 255-288.

[Sh 211] -----, Stationary logic II: Comparison with other logics, Notre Dame J. of Formal Logic,

[Sh 220] -----, Existence of many  $L_{\infty, \lambda}$ -equivalent non-isomorphic models of  $T$  of power  $\lambda$ , Proc. of the Model Theory Conference Trento June 1986, ed G. Cherlin, A. Marcja, Annals of Pure and Applied Logic, 34(1987), 291-310.

[Sh 228] -----, On the  $no(M)$  for  $M$  of singular power, A Springer-Verlag Lecture Notes Volume, Vol. 1182(1986), 120-134.

[Sh 250] -----, Some notes on iterated forcing with  $2^{\aleph_0} > \aleph_2$ , Notre Dame J. of Formal Logic, 29(1988), 1-17.



## REFERENCES.

- [EHR] Paul Erdős, Andras Hajnal, and Richard Rado. Partition relations for cardinal numbers. *Acta Math. Acad. Sci. Hung.*, **16**:93–196, 1965.
- [G] Kurt Gödel. *The consistency of the axiom of choice and the generalized continuum-hypothesis with the axioms of set theory*. Princeton University Press, 1940.
- [Ma] Edward Marczewski. Séparabilité et multiplication cartésienne des espaces topologiques. *Fundamenta Math.*, **34**:127–143, 1947.
- [MkSh 166] Alan H. Mekler and Saharon Shelah. Stationary logic and its friends. I. *Notre Dame Journal of Formal Logic*, **26**:129–138, 1985. Proceedings of the 1980/1 Jerusalem Model Theory year.
- [Sh 18] Saharon Shelah. On models with power-like orderings. *Journal of Symbolic Logic*, **37**:247–267, 1972.
- [Sh 129] Saharon Shelah. On the number of nonisomorphic models of cardinality  $\lambda$ ,  $L_{\infty\lambda}$ -equivalent to a fixed model. *Notre Dame Journal of Formal Logic*, **22**:5–10, 1981.
- [Sh 125] Saharon Shelah. The consistency of  $\text{Ext}(G, \mathbf{Z}) = \mathbf{Q}$ . *Israel Journal of Mathematics*, **39**:74–82, 1981.
- [Sh 133] Saharon Shelah. On the number of nonisomorphic models in  $L_{\infty,\kappa}$  when  $\kappa$  is weakly compact. *Notre Dame Journal of Formal Logic*, **23**:21–26, 1982.
- [Sh:b] Saharon Shelah. *Proper forcing*, volume 940 of *Lecture Notes in Mathematics*. Springer-Verlag, Berlin-New York, xxix+496 pp, 1982.
- [Sh 189] Saharon Shelah. On the possible number  $\text{no}(M) =$  the number of nonisomorphic models  $L_{\infty,\lambda}$ -equivalent to  $M$  of power  $\lambda$ , for  $\lambda$  singular. *Notre Dame Journal of Formal Logic*, **26**:36–50, 1985.
- [Sh 199] Saharon Shelah. Remarks in abstract model theory. *Annals of Pure and Applied Logic*, **29**:255–288, 1985.
- [Sh 228] Saharon Shelah. On the  $\text{no}(M)$  for  $M$  of singular power. In *Around classification theory of models*, volume 1182 of *Lecture Notes in Mathematics*, pages 120–134. Springer, Berlin, 1986.
- [Sh 250] Saharon Shelah. Some notes on iterated forcing with  $2^{\aleph_0} > \aleph_2$ . *Notre Dame Journal of Formal Logic*, **29**:1–17, 1988.