HANF NUMBER FOR THE STRICTLY STABLE CASES SH1048

SAHARON SHELAH

Abstract. Suppose $\mathbf{t} = (T, T_1, p)$ is a triple of two theories $T \subseteq T_1$ in vocabularies $\tau \subseteq \tau_1$ (respectively) of cardinality λ and a τ_1-type p over the empty set; in the main case here is with T stable. We show the Hanf number for the property: "there is a model M_1 of T_1 which omits p, but $M_1{\restriction}\tau$ is saturated" is larger than the Hanf number of $L_{\lambda^+,\kappa}$ but smaller than the Hanf number of $\mathbb{L}_{(2^\lambda)^+,\kappa}$ when T is stable with $\kappa = \kappa(T)$. In fact, we characterize the Hanf number of $\mathbf{t}$ when we fix (T, λ) where T is a first order complete, $\lambda \geq |T|$ and demand $|T_1| \leq \lambda$.

Date: June 13, 2018.

2010 *Mathematics Subject Classification.* Primary: 03C75, 03C45; Secondary: 03C55, 03C50.

Key words and phrases. Model theory, infinitary logics, Hanf numbers, stable theories.

Partially supported by European Research Council Grant #338821. The author thanks Alice Leonhardt for the beautiful typing. First typed December 28, 2012.

§ 0. Introduction

§ 0(A). Background on Results.

This continues papers of Baldwin-Shelah, starting from a problem of Newelski [New12] concerning the Hanf number described in the abstract for classes $\mathbf{t} \in$
{b2} $\mathbf{N}_{\lambda,T}$ (defined formally in 1.1). They showed in [BlSh:958] that with no stability restriction the Hanf number is essentially equal to the Löwenheim number of second order logic and in [BlSh:992] showed that for superstable T it is bigger than the Hanf number of $\mathbb{L}_{(2^\lambda)^+,\aleph_0}$ but it is smaller than $\mathbb{L}_{\beth_2(\lambda)^+,\aleph_0}$.

Our original aim was to deal with the case where T is a stable theory and concentrate on the strictly stable case (i.e. stable not superstable).

However, we ask a stronger question.

{x2} *Question* 0.1. Fix a complete first order theory T and a cardinal $\lambda \geq |T|$, what is $\sup\{H(\mathbf{t}) : H(\mathbf{t}) < \infty$ and $\mathbf{t}$ as above with $T_{\mathbf{t}} = T$ and $|T_{\mathbf{t},1}| \leq \lambda$, i.e. belongs to
{b2} $\mathbf{N}_{\lambda,T}$ from 1.1(1)$\}$, where $H(\mathbf{t})$ is the supremum of the cardinalities of models in $\mathrm{Mod}_{\mathbf{t}}$.

Clearly this is a considerably more ambitious question. We give a quite complete answer. For T strictly stable, our original case, it appears that only the cardinals $|T|, \kappa(T)$ and a derived Boolean Algebra $\mathbb{B}(T)$ of cardinality $|D(T)|$, and a little more. In fact, for any T, the little more is the truth value of ($2^{\aleph_0} > |D(T)| > |T| \wedge$"$T$ unstable in $|D(T)|$" $\wedge$ (T superstable).

Here the infinitary logic $\mathbb{L}_{\lambda^+,\kappa}$ is central.

A major point here is to deal abstractly with what is essentially the Boolean algebra of formulas over the empty set, $\mathbb{B}_T$ (so modulo T of course). We introduce
{b4} in Definition 1.5 the logics $\mathbb{L}_{\lambda^+,\kappa}[\mathbb{B}]$ where $\mathbb{B} = \mathbb{B}_T$, the members of the Boolean algebra (i.e. formulas from $\mathbb{L}(\tau_T)$) are coded by elements of the model and the union of these logics over the relevant $\mathbb{B}$'s is called $\mathbb{L}^{\mathrm{ba}}_{\lambda^+,\kappa}$, moreover $\mathbb{L}^{\mathrm{ba}}_{\lambda,\kappa} = \mathbb{L}_{\lambda,\kappa}[\mathbb{B}^{\mathrm{fr}}_\lambda]$, see
{b5} below. Then in Observation 1.6(1) we note that

$$H(\mathbb{L}_{\lambda^+,\kappa}) \leq H(\mathbb{L}_{\lambda^+,\kappa}[\mathbb{B}]) \leq H(\mathbb{L}^{\mathrm{ba}}_{\lambda^+,\kappa}) \leq H(\mathbb{L}_{(2^\lambda)^+,\kappa}).$$

The main result shows that there is an exact equivalence between classes of the form $\mathbf{N}_{\lambda,T}$ and classes of the form $\mathrm{Mod}_\psi, \psi \in \mathbb{L}_{\lambda^+,\kappa}[\mathbb{B}]$ for $\mathbb{B}$ the Boolean Algebra formulas over the emptyset in T.

We thank John Baldwin, Daniel Palacin and a referee for helpful comments.

§ 0(B). Preliminaries.

Here for a first order complete T we define the relevant parameters; $\kappa(T), \mathbb{B}_T$ and quote characterization of saturation.

{a2} *Notation* 0.2. 1) τ is a vocabulary.
1A) T denotes a first order theory in $\mathbb{L}_{\tau(T)}, \tau_T = \tau(T)$ the vocabulary of T and T is usually complete.
2) $\bar{x}_{[u]} = \langle x_i : i \in u\rangle$, similarly $\bar{y}_{[u]}$; e.g. $\bar{x}_{[\alpha]} = \langle x_i : i < \alpha\rangle$.
3) $\mathbb{L}_{\lambda,\kappa}$ for $\lambda \geq \kappa$ is the logic where the language $\mathbb{L}_{\lambda,\kappa}(\tau)$ is the following set of formulas; it is the closure of the set of atomic formulas under negation, conjunction

of the form $\bigwedge\limits_{\alpha<\gamma} \varphi_\alpha, \gamma < \lambda$ and quantification $(\exists \bar{x}_{[u]})\varphi$ where $u \in [\kappa]^{<\kappa}$ (really just $(\exists \bar{x}_{[\varepsilon]})\varphi$ for $\varepsilon < \kappa$ suffice) but every formula has $< \kappa$ free variables.
4) Let $\mathbb{B}$ denote a Boolean Algebra and $\mathrm{uf}(\mathbb{B})$ the set of ultra-filters of $\mathbb{B}$.
5) Let $\mathbf{t}$ denote an object as in Definition 1.1 below. {b2}
6) For a theory T let Mod_T be the class of models of T.

Recall

{b13}

Definition 0.3. Let T be a first order complete stable theory.
1) $\kappa(T)$ is the minimal κ such that: if $A \subseteq M_* \in \mathrm{Mod}_T$ and $p \in \mathbf{S}(A, M)$ then there is $B \subseteq A$ of cardinality $< \kappa$ such that p does not fork over B, see [Sh:c, Ch.III].
2) Let $\kappa_r(T) = \min\{\kappa : \kappa \text{ regular } \geq \kappa(T)\}$ so $\kappa_r(T)$ is the minimal regular κ such that T is stable in λ whenever $\lambda = \lambda^{<\kappa} + 2^{|T|}$, see [Sh:c, Ch.III].
3) Let $\lambda(T)$ be the minimal λ such that T is stable in λ, that is $[M \models T, \|M\| \leq |T| + \aleph_0 \Rightarrow |\mathbf{S}(M)| \leq \lambda]$, see [Sh:c, Ch.III,§5,§6].
4) $D_m(T) = \{\mathrm{tp}(\bar{a}, 0, M) : \bar{a} \in {}^m M \text{ and } M \models T\}$ and $D(T) = \bigcup\limits_m D_m(T)$.
5) Let $\mathrm{EQ}_T = \{\varphi(\bar{x}_{[n]}, \bar{y}_{[n]}) : n < \omega, \varphi \in \mathbb{L}(\tau_T)$ and for every model M of T, $\{(\bar{a}, \bar{b}) : \bar{a}, \bar{b} \in M$ and $M \models \varphi[\bar{a}, \bar{b}]\}$ is an equivalence relation on ${}^n M$ with finitely many equivalent classes$\}$.
6) M is $\aleph_\varepsilon$-saturated <u>when</u> for every triple (b, A, N) satisfying $A \subseteq M \prec N, b \in N, A$ finite, some $b' \in M$ realizes the type $\{\varphi(x, b; \bar{a}) : \bar{a} \subseteq A, \varphi(x, y, \bar{a})$ is an equivalence relation with finitely many equivalence classes in M, equivalently b' realizes $\mathrm{stp}(b, A, N)\}$, see [Sh:c, Ch.III].

{b14}

Remark 0.4. By [Sh:c, Ch.III,§5,§6] we have that $\lambda(T) = |\mathrm{uf}(\mathbb{B}_{T^{\mathrm{eq}}})|^{<\kappa(T)}$. Furthermore, if T is superstable and unstable in $|T|$, <u>then</u> $|D(T)| < 2^{\aleph_0} = \lambda(T)$ and $\lambda(T) = |D(T)|^{<\kappa(T)}$.

The point is that by [Sh:c, Ch.III]:

{b18}

Fact 0.5. Let T be a complete first order stable theory and let $\lambda \geq \aleph_1 + |T|$ be an infinite cardinal. <u>Then</u> T has a saturated model of cardinality λ if and only if T is λ-stable.

Note that

{z6}

Observation 0.6. *For every Boolean Algebra $\mathbb{B}_1$ of cardinality $\leq \lambda$ and $\kappa \leq \lambda^+$ there is a Boolean Algebra $\mathbb{B}_2$ of cardinality λ such that $|\mathrm{uf}(\mathbb{B}_2)| = \Sigma\{|\mathrm{uf}(\mathbb{B}_1)|^\theta : \theta < \kappa\}$.*

Proof. If $|\mathbb{B}_1| = \lambda, \kappa = \theta^+, \theta \leq \lambda$ we define the Boolean Algebra $\mathbb{B}_2$ as the free product of θ copies of $\mathbb{B}_1$.

If κ is a limit cardinal $\leq \lambda, |\mathbb{B}_1| = \lambda$ let $\mathbb{B}_{2,\theta}$ be as above for $\theta < \kappa$ and $\mathbb{B}_2$ the disjoint sum of $\langle \mathbb{B}_{2,\theta} : \theta < \kappa \rangle$ so essentially except one ultrafilter, all ultrafilters on $\mathbb{B}_2$ are ultrafilters on some $\mathbb{B}_{2,\theta}$ so $\mathrm{uf}(\mathbb{B}_2) = 1 + \sum\limits_{\theta<\kappa} \mathrm{uf}(\mathbb{B}_{2,\theta})$. $\square_{0.6}$

{a4}

Definition 0.7. 1) For a model M and formula $\varphi(\bar{x}, \bar{y}) \in \mathbb{L}(\tau_M)$ and $\bar{a} \in {}^{\ell g(\bar{y})} M$ let $\varphi(M, \bar{a}) = \{\bar{b} \in {}^{\ell g(\bar{x})} M : M \models \varphi[\bar{b}, \bar{a}]\}$.
2) For a model $M, \mathbb{B}_{M,m}$ is the Boolean Algebra of subsets of ${}^m M$ consisting of the sets $\{\varphi(M) : \varphi = \varphi(\bar{x}_{[m]})\}$.

2A) $\mathbb{B}_{T,m}$ for $T = \mathrm{Th}(M)$ is the Boolean Algebra of the formulas $\varphi(\bar{x}_{[m]}), \mathbb{L}(\tau_T)$ modulo equivalence over T, so $\varphi_1(\bar{x}_{[m]}) \le \varphi_2(\bar{x}_{[m]})$ iff $T \vdash$ "$\varphi_1(\bar{x}_{[m]}) \to \varphi_2(\bar{x}_{[m]})$", so the elements are actually $\varphi(\bar{x}_{[m]})/\equiv_T$.
3) Let $\bar{\mathbb{B}}_M = \langle \mathbb{B}_{M,m} : m < \omega \rangle$; abusing notation let $\mathrm{uf}(\bar{\mathbb{B}}_M) = \bigcup\limits_m \mathrm{uf}(\mathbb{B}_{M,m})$. Similarly with T instead of M, also below.
3A) Let $\mathbb{B}_M$ be the direct sum of $\langle \mathbb{B}_{M,m} : m < \omega \rangle$ so $\langle 1_{\mathbb{B}_{M,m}} : m < \omega \rangle$ be a maximal antichain of $\mathbb{B}_M, \mathbb{B}_M \restriction \{x \in \mathbb{B}_M : x \le 1_{\mathbb{B}_{M,m}}\} = \mathbb{B}_{M,m}$ and $\cup\{\mathbb{B}_{M,m} : m < \omega\}$ generates $\mathbb{B}_M$. Let $\mathrm{tr}-\mathrm{ufil}(\mathbb{B}_M)$ = the ultrafilter of $\mathbb{B}_M$ disjoint to $\{1_{\mathbb{B}_{M,n}} : n < \omega\}$ and let $\mathrm{uf}^-(\mathbb{B}_M) = \mathrm{uf}(\mathbb{B}_M) \backslash \{\mathrm{tr}-\mathrm{ufil}(\mathbb{B}_M)\}$, ($\mathrm{tr}-\mathrm{ufil}$ stands for trivial ultra-filter).
4) Let $\lambda'(M)$ be the cardinality of $\mathrm{uf}(\mathbb{B}_M)$.
5) Let $\mathbb{B}^{\mathrm{fr}}_\lambda$ be the Boolean algebra generated freely by $\{\mathbf{a}_\alpha : \alpha < \lambda\}$ so $\mathrm{uf}(\mathbb{B}^{\mathrm{fr}}_\lambda)$ has cardinality 2^λ.

{a5} *Remark* 0.8. We may be interested in the Boolean Algebra of formulas which are almost over $\emptyset$, i.e. $\varphi(\bar{x}_m, \bar{a}), \bar{a} \in {}^{\ell g(\bar{y})}M$ where $\varphi(\bar{x}_m, \bar{y}) \in \mathbb{L}(\tau_T)$ satisfies: $\varphi(\bar{x}_m, \bar{y})$,
{b13} for some $\vartheta(\bar{x}_m, \bar{y}_m) \in \mathrm{EQ}^m_M$, see 0.3(5), we have $M \models (\forall \bar{z})(\forall \bar{x}_m, \bar{y}_m)[\vartheta(\bar{x}_m, \bar{y}_m) \to (\varphi(\bar{x}_m, \bar{z}) \equiv \varphi_n(\bar{y}_m, \bar{z})]$.

But this is not necessary here.

{a6} **Observation 0.9.** *1) $\mathbb{B}_{M,m}$ essentially depend just on $\mathrm{Th}(M)$, i.e. if $T = \mathrm{Th}(M)$ then $\mathbb{B}_{M,m}$ is isomorphic to $\mathbb{B}_{T,m}$ by $\varphi(\bar{x}_{[m]}) + \mathbb{L}(\tau_T) \Rightarrow \mathbf{j}(\varphi(M)) = \varphi(\bar{x}_{[m]})/\equiv_T$, so $\lambda'(T)$ is well defined.*
{a4} *2) Similarly for other notions from Definition 0.7.*
3) $\mathrm{uf}^-(\mathbb{B}_M), \mathrm{uf}(\mathbb{B}_M)$ has the same cardinality, in fact, there is a natural one-to-one mappping π from $\mathrm{uf}(\bar{\mathbb{B}}_M)$ onto $\mathrm{uf}^-(\mathbb{B}_M)$ such that $D \in \mathrm{uf}(\mathbb{B}_{M,m}) \Rightarrow \pi(D) = \{a \in \mathbb{B}_{M,m} : a \cap 1_{\mathbb{B}_{M,m}} \in D\}$.

Recall by Lemma [Sh:c, Ch.III,3.10]:

{a9} **Fact 0.10.** Let T be a stable (first order complete) theory, $\kappa = \kappa(T)$ and M is an uncountable model of T. Then M is saturated iff

Case 1: $\kappa > \aleph_0$

(a) if $\mathbf{I} \subseteq M$ is an infinite indiscernible set then there is an indiscernible set $\mathbf{J} \subseteq M$ extending $\mathbf{I}$ of cardinality $\|M\|$

(b) M is κ-saturated.

Case 2: $\kappa = \aleph_0$

(a)′ if $A \subseteq M$ is finite and $a \in M \backslash \mathrm{acl}(A)$ then there is an indiscernible set $\mathbf{J}$ over A in M based on A such that $a \in \mathbf{J}$ and $\mathbf{J}$ is of cardinality $\|M\|$

{b13} (b)′ M is $\aleph_\varepsilon$-saturated, see [Sh:c] or Definition 0.3(6).

{a12} **Fact 0.11.** Assume T is a stable (first order complete) theory.
1) If $\kappa(T) > \aleph_0$ then $\lambda(T) = |D(T)|^{<\kappa_r(T)}$.
2) If $\kappa(T) = \aleph_0$ then $\lambda(T)$ is $|D(T)|$ or $\lambda(T) = 2^{\aleph_0} + |D(T)|$ and

$(\mathrm{st})_T$ for some finite $A \subseteq M, M \in \mathrm{Mod}_T$, the set $\{\mathrm{stp}(a, A) : a \in M\}$ has cardinality continuum.

{a16}

Definition 0.12. 1) For a cardinal θ let $T^{\rm eq}_\theta$ be the model completion of $T^{{\rm eq},0}_\theta$, see below.
2) Let $\tau^{\rm eq}_\theta = \{E_i : i < \theta\}, E_i$ a two-place predicate.
3) Let $T^{\rm eq}_\theta$ be the universal theory included in $\mathbb{L}(\tau^{\rm eq}_\theta)$ such that: for a $\tau^{\rm eq}_\theta$-model $M, M \models T^{\rm eq}_\theta$ $\underline{\rm iff}$ E^M_i is an equivalence relation and E^M_j refines E^M_i for $i < j < \theta$.

§ 1. The frame

First, we define here $\mathbf{N}_{\lambda,T}$, the set of $\mathbf{t}$ from the abstract when we fix T, λ and for $\mathbf{t} \in \mathbf{N}_{\lambda,T}$ we define the class of models $\mathrm{Mod}_{\mathbf{t}}$ (in 1.1,1.2) and give easy properties (in 1.3, 1.4). Second, we deal with the logics $\mathbb{L}_{\lambda,\kappa}[\mathbb{B}]$ via which we shall characterize the Hanf number of $\mathbf{N}_{\lambda,T}$ and look at the relation amongst such logics (see 1.5, 1.9). Then we deal with representations, e.g. how $\psi \in \mathbb{L}_{\lambda^+,\kappa}$ can be translated to models of first order T, with extra demands (see 1.10 - 1.14). Last, we look at order between the $\mathbb{B}$'s.

{b2} **Definition 1.1.** 1) For T complete first order stable theory and $\lambda \geq |T|$ let $\mathbf{N}_{\lambda,T}$ be the class of triples $\mathbf{t} = (T, T_1, p) = (T_{\mathbf{t}}, T_{1,\mathbf{t}}, p_{\mathbf{t}})$ such that:

- (a) $T_{\mathbf{t}} = T$
- (b) $T_1 \supseteq T$ is a first order theory and $|\tau(T_1)| \leq \lambda$
- (c) $p(x)$ is an $\mathbb{L}(\tau_{T_1})$-type.

1A) For $\mathbf{t}$ as above we say $M_1 \models \mathbf{t}$ or $M_1 \in \mathrm{Mod}_{\mathbf{t}}$ or M_1 is a model of $\mathbf{t}$ <u>when</u>:

- (a) $M_1 \models T_{1,\mathbf{t}}$ and M_1 a τ_{T_1}-model
- (b) M_1 omits the type $p_{\mathbf{t}}(x)$
- (c) $M_1 \restriction \tau_T$ is saturated.

1B) Omitting T means: for some T such that $|T| \leq \lambda$.
2) Let $\mathrm{spec}_{\mathbf{t}} = \{\|M\| : M \models \mathbf{t}\}$ for $\mathbf{t} \in \mathbf{N}_{\lambda,T}$.
3) The Hanff number $H(\mathbf{N}_{\lambda,T})$ is the minimal μ such that: if $\mathbf{t} \in \mathbf{N}_{\lambda,T}$ and $\mathbf{t}$ has
{b4} a model of cardinality $\geq \mu$ <u>then</u> $\mathbf{t}$ has models of arbitrarily large cardinality; see 1.5(3).
3A) Equivalently, $H(\mathbf{N}_{\lambda,T}) = \sup\{H(\mathbf{t}) : H(\mathbf{t}) < \infty, \mathbf{t} \in \mathbf{N}_{\lambda,T}\}$ where $H(\mathbf{t}) = \sup\{\|M\|^+ : M \in \mathrm{Mod}_{\mathbf{t}}\}$.
4) $\lambda(\mathbf{t}) := \lambda(T_{\mathbf{t}}) + |T_{1,\mathbf{t}}|$.

{b2g}
{b2} **Convention 1.2.** Below $\mathbf{t}, T, T_1, p, \lambda$ are as in Definition 1.1 if not said otherwise and then $\kappa = \kappa_r(T)$ as in 0.3.

{b13}
{b3} **Claim 1.3.** *1) If $M \in \mathrm{Mod}_{\mathbf{t}}$ has cardinality μ <u>then</u> $\mu = \mu^{<\kappa(T)} + |\lambda(T)|$, i.e. $\mu \in \mathrm{spec}_{\mathbf{t}} \Rightarrow \mu = \mu^{<\kappa(T)} + \lambda(T)$.*
2) If $M \in \mathrm{Mod}_{\mathbf{t}}$ and $\lambda(\mathbf{t}) \leq \mu = \mu^{<\kappa(T)} < \|M\|$ and $A \subseteq M$ is of cardinality μ <u>then</u> for some N we have:

- (a) $N \in \mathrm{Mod}_{\mathbf{t}}$
- (b) $A \subseteq N \prec M$
- (c) *N has cardinality μ.*

{b18} *Proof.* 1) By 0.5.
2) Note that also $\mu = \mu^{<\kappa_r(T)}$ by cardinal arithmetic and hence $\kappa_r(T) \leq \mu$; we choose M_i by induction on $i < \kappa_r(T)$ such that:

- (a) if i is even then $M_i \prec M$ and $\|M_i\| = \mu$
- (b) if i is odd then $M_i \restriction \tau(T_{\mathbf{t}}) \prec M \restriction \tau(T_{\mathbf{t}}), \|M_i\| = \mu$ and M_i is saturated
- (c) if $j < i$ then $A \cup |M_j| \subseteq |M_i|$.

There is no problem to carry the induction and then $M' = \cup\{M_{2i} : i < \kappa_r(T)\}$ is as required: $M' \prec M$ by (a)+(c) and Tarski-Vaught, $\|M'\| = \mu$ since $\mu^{<\kappa_T(T)} = \mu$ and $M' \restriction \tau(T)$ is saturated by (b) + (c) and [Sh:c, Ch.III]. $\square_{1.3}$

{b3f}

Conclusion 1.4. *For understanding the Hanf number of* $\mathbf{t}$*, it is enough to consider cardinals* $\mu = \mu^{<\kappa(T)} \geq \lambda(\mathbf{t})$.

Now we turn to the logics of the form $\mathbb{L}_{\lambda^+,\kappa}[\mathbb{B}]$; first we define them.

{b4}

Definition 1.5. 1) Assume

- (a) $\lambda \geq \kappa = \mathrm{cf}(\kappa)$
- (b) $\mathbb{B}$ a Boolean Algebra of cardinality $\leq \lambda$ and let $\mathrm{uf}(\mathbb{B})$ be the set of ultrafilters on $\mathbb{B}$.

Then

- (α) Let $\mathrm{voc}_\lambda[\mathbb{B}]$ be the class of vocabularies τ of cardinality $\leq \lambda$ such that $c_b \in \tau$ individual constant for $b \in \mathbb{B}$, and $P, Q \in \tau$ unary predicates and $R \in \tau$ binary and τ may have additional signs.
- (β) For $\tau \in \mathrm{voc}_\lambda[\mathbb{B}]$ let $\mathbb{L}_{\lambda^+,\kappa}[\mathbb{B}](\tau)$ be the set of sentences $\psi \in \mathbb{L}_{\lambda^+,\kappa}(\tau)$ but we stipulate that from ψ we can reconstruct the triple $(\lambda^+, \kappa, \mathbb{B})$ hence $\mathbb{L}_{\lambda^+,\kappa}[\mathbb{B}]$.

[Note that ψ has $\leq \lambda$ sub-formulas]:

- (γ) omitting τ means $\tau = \tau_\psi$ is the minimal $\tau \in \mathrm{voc}_\lambda[\mathbb{B}]$ such that $\psi \in \mathbb{L}_{\lambda^+,\kappa}[\mathbb{B}](\tau)$, so $\mathbb{L}_{\lambda^+,\kappa}[\mathbb{B}]$ is essentially a logic.

2) For $\tau \in \mathrm{voc}_\lambda[\mathbb{B}]$ and $\psi \in \mathbb{L}_{\lambda^+,\kappa}[\mathbb{B}](\tau)$ let $\mathrm{Mod}^1_\psi[\mathbb{B}]$ be the class of models M of ψ (which are τ_ψ-models if not said otherwise) such that (note: clauses (a)-(d) can be expressed in $\mathbb{L}_{\lambda^+,\aleph_0}$, but when $|\mathrm{uf}(\mathbb{B})| > \lambda$ not so clause (e))

- (a) $P^M = \{c^M_b : b \in \mathbb{B}\}$
- (b) $\langle c^M_b : b \in \mathbb{B}\rangle$ are pairwise distinct
- (c) $R \subseteq P^M \times Q^M$
- (d) for every $a \in Q^M$ the set $\mathrm{uf}^M(a) := \{b \in \mathbb{B} : M \models c_b R a\}$ belongs to $\mathrm{uf}(\mathbb{B})$ and if $a_1 \neq a_2 \in Q^M$ then $\mathrm{uf}^M(a_1) \neq \mathrm{uf}^M(a_2)$
- (e) for every $u \in \mathrm{uf}(\mathbb{B})$ there is one and only one $a \in Q^M$ such that $M \models \bigwedge\limits_{i<\lambda} (c_b R a)^{\mathrm{if}(b \in u)}$, (by (d) unique).

3) Let $\mathrm{Mod}^2_\psi[\mathbb{B}]$ be the class of $M \in \mathrm{Mod}^1_\psi[\mathbb{B}]$ such that:

- (f) $\|M\| = \|M\|^{<\kappa}$ and (follows) $\|M\| \geq |\mathrm{uf}(\mathbb{B})|$.

4) For $\iota = 1, 2$ and $\psi \in \mathbb{L}_{\lambda^+,\kappa}[\mathbb{B}]$ let $\mathrm{spec}^\iota_\psi[\mathbb{B}] = \{\|M\| : M \in \mathrm{Mod}^\iota_\psi[\mathbb{B}]\}$.
4A) Writing $\mathrm{Mod}^\iota_\psi, \mathrm{spec}^\iota_\psi$ we mean $\iota \in \{1, 2\}$ and may omit ι when $\iota = 2$ (because this is the main case for us), see 1.6(0).

{b5}

5) Let $H(\mathbb{L}_{\lambda^+,\kappa}[\mathbb{B}])$ be the first μ such that: if $\psi \in \mathbb{L}_{\lambda^+,\kappa}[\mathbb{B}]$ and there is $M \in \mathrm{Mod}_\psi[\mathbb{B}]$ of cardinality $\geq \mu$ then $\{\|M\| : M \in \mathrm{Mod}_\psi[\mathbb{B}]\}$ is an unbounded class of cardinals.

6) Let $\mathbb{L}^{\rm ba}_{\lambda^+,\kappa}$ be $\cup\{\mathbb{L}_{\lambda^+,\kappa}[\mathbb{B}] : \mathbb{B}$ a Boolean[1] Algebra of cardinality $\le \lambda\}$ so every sentence of $\mathbb{L}^{\rm ba}_{\lambda^+,\kappa}(\tau)$ is a sentence in $\mathbb{L}_{\lambda^+,\kappa}[\mathbb{B}](\tau)$ for some $\mathbb{B}$ as above; so we may stipulate that the set of elements of $\mathbb{B}$ is a cardinal $\le \lambda$ and $c_i \in \tau$ for $i < \lambda$.
7) We define $H(\mathbb{L}^{\rm ba}_{\lambda^+,\kappa})$ similarly; yes, this is just $\sup\{H(\mathbb{L}_{\lambda^+,\kappa}[\mathbb{B}]) : \mathbb{B}$ as above$\}$.

Having defined the class of $\mathbf{t}$'s and the class of models of $\mathbf{t}, {\rm Mod}_{\mathbf{t}}$ and their spectrum we should now try to understand the order between them.

{b5}
Observation 1.6. *Let $\mathbb{B}$ be a Boolean Algebra of cardinal $\le \lambda$ and $\kappa \le \lambda^+$.*
{b4} *0) In the Definition 1.5(5) of $H(\mathbb{L}_{\lambda^+,\kappa}[\mathbb{B}])$ it does not matter if we use ${\rm Mod}^1_\psi[\mathbb{B}]$ or ${\rm Mod}^2_\psi[\mathbb{B}]$.*
1) We have $H(\mathbb{L}_{\lambda^+,\kappa}) \le H(\mathbb{L}_{\lambda^+,\kappa}[\mathbb{B}]) \le \mathbb{L}_{\lambda^+,\kappa}[\mathbb{B}^{\rm fr}_\lambda] = H(\mathbb{L}^{\rm ba}_{\lambda^+,\kappa}) < H(\mathbb{L}_{(2^\lambda)^+,\kappa})$.
{a4} *1A) If $\mathbb{B}^{\rm fr}_\lambda$ is the free Boolean Algebra of cardinality λ from 0.7(5) and $\kappa = \aleph_0$ then $H(\mathbb{L}_{\lambda^+,\kappa}) < \beth_{(2^\lambda)^+} < H(\mathbb{L}_{\lambda^+,\kappa}[\mathbb{B}^{\rm fr}_\lambda])$.*
1B) $H(\mathbb{L}^{\rm ba}_{\lambda^+,\kappa}) < H(\mathbb{L}_{(2^\lambda)^+,\kappa})$.
2) For every $\mu < H(\mathbb{L}_{\lambda^+,\kappa}[\mathbb{B}])$ we have $2^\mu < H(\mathbb{L}_{\lambda^+,\kappa}[\mathbb{B}])$ hence $H(\mathbb{L}_{\lambda^+,\kappa}[\mathbb{B}])$ is a strong limit cardinal of cofinality $> \lambda$.
3) If $\psi \in \mathbb{L}_{\lambda^+,\kappa}[\mathbb{B}]$ and $H(\mathbb{L}_{\lambda^+,\kappa}[\mathbb{B}]) \le \sup\{\|M\| : M \in {\rm Mod}_\psi[\mathbb{B}]\}$ then $\infty = \sup\{\|M\| : M \in {\rm Mod}_\psi[\mathbb{B}]\}$.
4) Like part (2) for $H(\mathbb{L}^{\rm ba}_{\lambda^+,\kappa})$.
5) Like part (3) for $\psi \in \mathbb{L}^{\rm ba}_{\lambda^+,\kappa}$ and ${\rm Mod}^{\rm ba}_\psi$.
6) For every $\psi_1 \in \mathbb{L}_{\lambda^+,\kappa}[\mathbb{B}]$ there are $\psi_2, \psi'_2, \psi''_2 \in \mathbb{L}_{\lambda^+,\kappa}[\mathbb{B}]$ such that:

- (a) ${\rm spec}^1_{\psi_2}[\mathbb{B}] = \{\mu : \mu = \mu^{<\kappa} \in {\rm spec}^1_{\psi_1}[\mathbb{B}]\} = {\rm spec}^2_{\psi_1}[\mathbb{B}]$ *and*[2]
- (b) ${\rm spec}^1_{\psi'_2}[\mathbb{B}] = \{\mu^{<\kappa} : \mu \in {\rm spec}^1_{\psi_1}[\mathbb{B}]\}$ *and*
- (c) ${\rm spec}^1_{\psi''_2}[\mathbb{B}] = \{\mu : \mu \ge \lambda$ *and* $\mu \in {\rm spec}^1_{\psi_1}[\mathbb{B}]\}$.

Proof. 0) First, as the Hanf number is $> 2^\lambda \ge |{\rm uf}(\mathbb{B})|$, we can ignore models of cardinality $< 2^\lambda$. Second, if $\psi_1 \in \mathbb{L}_{\lambda,\kappa}[\mathbb{B}](\tau)$ and $\sup({\rm spec}^1_{\psi_1}) < \infty$ then $\sup({\rm spec}^2_{\psi_1}) \le \sup({\rm spec}^1_{\psi_1}) \le \sup({\rm spec}^2_{\psi_1})^{<\kappa} < \infty$.

{b3} Why? the first inequality because ${\rm spec}^1_\psi \subseteq {\rm spec}^2_\psi$; the second inequality by 1.3(1). We can conclude that the Hanf number of the logic $\mathbb{L}_{\lambda^+,\kappa}[\mathbb{B}]$ using ${\rm Mod}^1_\psi$ is smaller or equal to the Hanf number of the logic $\mathbb{L}_{\lambda^+,\kappa}[\mathbb{B}]$ using ${\rm Mod}^2_\psi$. Alternatively, if $\psi_1 \in \mathbb{L}_{\lambda^+,\kappa}[\mathbb{B}]$ then by clause (b) of part (6) there is $\psi'_2 \in \mathbb{L}_{\lambda^+,\kappa}[\mathbb{B}]$ such that $\sup({\rm spec}^1_{\psi_1}) < \infty \Rightarrow \sup({\rm spec}^1_{\psi_1}) \le \sup({\rm spec}^2_{\psi'_2}) < \infty$, hence the Hanf number using ${\rm spec}^1_\psi$'s is $\le$ the Hanf number using ${\rm spec}^2_\psi$'s. Moreover, above we get $\sup({\rm spec}^1_{\psi_1}) \le \sup({\rm spec}^2_{\psi'_2}) = \sup({\rm spec}^1_{\psi'_2})$ as ${\rm spec}^2_{\psi'_2} = {\rm spec}^1_{{\rm spec}'_2}$.

On the other hand, by clause (a) of part (6) if $\psi_1 \in \mathbb{L}_{\lambda,\kappa}[\mathbb{B}]$ then there is $\psi_2 \in \mathbb{L}_{\lambda,\kappa}[\mathbb{B}]$ such that ${\rm spec}^1_{\psi_2} = {\rm spec}^2_{\psi_1}$ so $\sup({\rm spec}^1_{\psi_1}) < \infty \Rightarrow \sup {\rm spec}^2_{\psi_1} = \sup {\rm spec}^1_{\psi_2} < \infty$ so also the other inequality holds.
1) For the first inequality "$H(\mathbb{L}_{\lambda^+,\kappa}) \le H(\mathbb{L}_{\lambda^+,\kappa}[\mathbb{B}])$", see the definitions of $\mathbb{L}_{\lambda^+,\kappa}[\mathbb{B}]$.
{b11} For the second inequality, "$H(\mathbb{L}_{\lambda^+,\kappa}[\mathbb{B}]) \le H(\mathbb{L}_{\lambda^+,\kappa}[\mathbb{B}^{\rm fr}_\lambda])$" use 1.9(2)(a) below. For the third inequality, "$H(\mathbb{L}_{\lambda^+,\kappa}[\mathbb{B}^{\rm fr}_\lambda]) = H(\mathbb{L}^{\rm ba}_{\lambda^+,\kappa})$" use the definition of the latter

[1]So every sentence $\psi \in \mathbb{L}^{\rm ba}_{\lambda^+,\kappa}$ fixes a Boolean Algebra $\mathbb{B}$ as above and a vocabulary of cardinality $\le \lambda$ from ${\rm voc}_\lambda[\mathbb{B}]$ as described.

[2]Recall that if $\mu > 2^{<\kappa}$ then $(\mu^{<\kappa})^{<\kappa} = \mu$, see [Sh:g].

and the second inequality. For the fourth inequality, "$H(\mathbb{L}^{\rm ba}_{\lambda^+,\kappa}) < H(\mathbb{L}_{(2^\lambda)^+,\aleph_0})$", see part (1B); so the inequality holds as every model M satisfying $\lambda \geq \|M\| + |\tau_M|$ can be characterized up to isomorphism by some $\psi \in \mathbb{L}_{(2^\lambda)^+,\kappa}$.
1A) The first inequality "$H(\mathbb{L}_{\lambda^+,\kappa}) < \beth_{(2^\lambda)^+}$" holds, e.g. by Theorem 5.4 and 5.5 of [Sh:c, Ch.VII,§5] recalling $\kappa = \aleph_0$. The second inequality "$\beth_{(2^\lambda)^+} < H(\mathbb{L}_{\lambda^+,\kappa}[\mathbb{B}^{\rm fr}_\lambda])$" holds by the third relation, i.e. the equality in part (1) and part (1B).
1B) Let $\mathbf{K}_{\lambda^+,\kappa}$ be the class of pairs $(\psi,\mathbb{B})$ such that $\mathbb{B}$ is a Boolean Algebra of cardinality $\leq \lambda, \psi \in \mathbb{L}_{\lambda^+,\kappa}[\mathbb{B}]$. For $(\psi,\mathbb{B}) \in \mathbf{K}_{\lambda^+,\kappa}$ let $H(\psi,\mathbb{B}) = \cup\{\mu^+ : \mu \in \mathrm{spec}^2_\psi(\mathbb{B})\}$. Clearly up to isomorphism (of vocabularies) $\mathbf{K}_{\lambda^+,\kappa}$ has cardinality $\leq 2^\lambda$ and hence $\mathbf{C}_{\lambda^+,\kappa} := \{H(\psi,\mathbb{B}) : (\psi,\mathbb{B}) \in \mathbf{K}_{\lambda^+,\kappa}\}$ has cardinality $\leq 2^\lambda$. So let $\langle(\psi_i,\mathbb{B}_i) : i < 2^\lambda\rangle$ be such that $(\psi_i,\mathbb{B}_i)$ is as above and $\mathbf{C}_{\lambda^+,\kappa}\backslash\{\infty\} = \{\mu_i : i < 2^\lambda\}$ where $\mu_i = H(\psi_i,\mathbb{B}_i) = \cup\{\mu^+ : \mu \in \mathrm{spec}^1_{\psi_i}[\mathbb{B}_i]\}$ for $i < 2^\lambda$. Now we can find $\psi \in \mathbb{L}_{(2^\lambda)^+,\kappa}$ such that $M \models \psi$ iff

- $(*)$ $<^M$ is a linear order of $|M|$ and for arbitrarily large $a \in M$ there are $i < 2^\lambda$ and $N \in \mathrm{Mod}^2_{\psi_i}[\mathbb{B}_i]$ with universe $\{b : b <^M a\}$.

Together with part (2) below. Clearly $\infty > \sup(\mathrm{spec}_\psi) = \max(\mathrm{spec}_\psi) = \cup\{\mu_i : i < 2^\lambda\}$ so we are done.
2) For any $\psi_1 \in \mathbb{L}_{\lambda^+,\kappa}[\mathbb{B}]$ we can find $\psi_2 \in \mathbb{L}_{\lambda^+,\kappa}[\mathbb{B}]$ such that $\tau_{\psi_1} \subseteq \tau_{\psi_2}, P_*, R_* \in \tau_{\psi_2}\backslash\tau_{\psi_1}$ are unary, binary predicates respectively and:

- $(*)_1$ $M_2 \in \mathrm{Mod}^\iota_{\psi_2}[\mathbb{B}]$ <u>iff</u>
  - $(M_2{\restriction}P^{M_2}_*{\restriction}\tau_{\psi_1}) \in \mathrm{Mod}_{\psi_1}[\mathbb{B}]$
  - $M_2 \models (\forall y,z)(\exists x)[P_*(x) \wedge (R(x,y) \equiv \neg R(x,z))]$ hence $|P^{M_2}_*| \leq \|M_2\| \leq 2^{|P_*(M_2)|}$.

Clearly

- $(*)_2$ for every $M_1 \in \mathrm{Mod}^1_{\psi_1}[\mathbb{B}]$ and $\mu = \mu^{<\kappa} \in [\|M_1\|, 2^{\|M_1\|}]$ there is $M_2 \in \mathrm{Mod}^1_{\psi_2}[\mathbb{B}]$ of cardinality μ.

Using $(*)_2$ this clearly suffices for the first statement. The second is easy, too.
3) As in the end of the proof of part (1B) replacing ψ_i by ψ,
4)-6) Left to the reader. $\square_{1.6}$

The following 1.7, 1.9 is another way to represent the logic $\mathbb{L}^{\rm ba}_{\lambda^+,\kappa}$ equivalently of the logic $\mathbb{L}_{\lambda^+,\kappa}[\mathbb{B}^{\rm fr}_\lambda]$, hence eventually to state the Hanf numbers. {b9}}

{b9}

Definition 1.7. 1) Let $\mathbb{L}^*_{\lambda^+,\kappa}$ be defined like $\mathbb{L}^{\rm ba}_{\lambda^+,\kappa}$, see 1.1(3) replacing $\langle c_b : b \in \mathbb{B}\rangle$ by $\langle c_i : i < \lambda\rangle$. {b2}
2) For $\psi \in \mathbb{L}^*_{\lambda^+,\kappa}$ let Mod^*_ψ be defined as in 1.5(1A),(2),(3) replacing $\mathrm{uf}(\mathbb{B})$ by $\mathscr{P}(\lambda)$. {b4}
3) Let $H(\mathbb{L}^*_{\lambda^+,\kappa})$ be defined like $H(\mathbb{L}_{\lambda^+,\kappa}[\mathbb{B}])$ in 1.5(5). {b4}
4) For $\psi \in \mathbb{L}^*_{\lambda^+,\kappa}$ let $\mathrm{spec}^*_\psi = \{\|M\| : M \in \mathrm{Mod}^*_\psi\}$; for transparency we will stipulate that from ψ we can reconstruct $\mathbb{L}^*_{\lambda^+,\kappa}$.

{b11g}

Remark 1.8. The following claim essentially tells us that for determining the Hanf number of $\mathbb{L}^{\rm ba}_{\lambda^+,\kappa}$, we may use the "worst" Boolean Algebra, $\mathbb{B}^{\rm fr}_\lambda$ and $\mathbb{L}_{\lambda^+,\kappa}[\mathbb{B}^{\rm fr}_\lambda]$ is essentially equal to $\mathbb{L}^*_{\lambda^+,\kappa}$.

Claim 1.9. *1) The parallel of 1.6 holds for $H(\mathbb{L}^*_{\lambda^+,\kappa})$.* {b11}
1A) There is $\psi \in \mathbb{L}^*_{\lambda^+,\kappa}$ such that if $M \in \mathrm{Mod}^*_\psi$ then $|P^M| = 2^\lambda$ and $<^M$ is a well ordering of P^M (and ψ has models). {b5}
2) Recall $\mathbb{B}^{\rm fr}_\lambda$ is the Boolean Algebra generated freely by λ generators

- (a) *for every Boolean algebra $\mathbb{B}_1$ of cardinality λ or just $\leq \lambda$ and $\psi_1 \in \mathbb{L}_{\lambda^+,\kappa}[\mathbb{B}_1]$ there is $\psi \in \mathbb{L}_{\lambda^+,\kappa}[\mathbb{B}^{\rm fr}_\lambda]$ such that $\mathrm{spec}^\iota_{\psi_1} \backslash 2^\lambda = \mathrm{spec}^\iota_\psi \backslash 2^\lambda$ for $\iota = 1,2$*
- (b) *$H(\mathbb{L}^{\rm ba}_{\lambda^+,\kappa}[\mathbb{B}_1]) \leq H(\mathbb{L}^{\rm ba}_{\lambda^+,\kappa}[\mathbb{B}^{\rm fr}_\lambda])$ for $\mathbb{B}_1$ as above*
- (c) *for every $\psi_1 \in \mathbb{L}^*_{\lambda^+,\kappa}$ there is $\psi_2 \in \mathbb{L}_{\lambda^+,\kappa}[\mathbb{B}^{\rm fr}_\lambda]$ such that $\{\|M\| : M \in \mathrm{Mod}^{\rm ba}_{\psi_1}\} = \{\|M\| : M \in \mathrm{Mod}^*_{\psi_2}[\mathbb{B}]\}$, that is $\mathrm{spec}^*_{\psi_1} = \mathrm{spec}_{\psi_2}[\mathbb{B}]$*
- (d) *for every $\psi_2 \in \mathbb{L}_{\lambda^+,\kappa}[\mathbb{B}^{\rm fr}_\lambda]$ there is $\psi_1 \in \mathbb{L}^*_{\lambda^+,\kappa}$ which are as in clause (c).*

Proof. Should be clear. $\square_{1.9}$

Next we have to connect those logics with first order T's. The easy part is to start with a Boolean Algebra $\mathbb{B}$ and construct a related T.

{b14}
Claim 1.10. *1) For every Boolean Algebra $\mathbb{B}$ of cardinality $\leq \lambda$ and cardinal $\kappa \leq \lambda^+$ there is $T = T^1_{\mathbb{B},\kappa}$ such that:*

$(*)_1$
- (a) *T is a first order complete and stable*
- (b) *$|T| = \lambda$ and $\kappa(T) = \kappa$*
- (c) *$\lambda(T)$ is the cardinality of $\mathrm{uf}[\mathbb{B}_T]$, in fact, $\mathbb{B}_T$ is not much more complicated than $\mathbb{B}$ but we shall not elaborate, see 1.16 below*

{b40}
- (d) *T has elimination of quantifiers.*

2) For $\mathbb{B}, \lambda, \kappa$ as above there is $T = T^2_{\mathbb{B},\kappa}$ such that:

$(*)_2$
- *(a), (b) as above*
- (c) *$\lambda(T) = \lambda + 2^{\aleph_0}$.*

Proof. Easy, but we elaborate.
1) We choose τ_*, T_0 by:

$(*)'_1$
- (a) $\tau_* = \tau_{\mathbb{B},\kappa} = \{P_b : b \in \mathbb{B}\} \cup \{Q_\theta : \theta < \kappa$ is infinite$\} \cup \{E_{\theta,i} : \theta < \kappa$ is infinite, $i < \theta\}$ where P_b, Q_θ are unary predicates, $E_{\theta,i}$ a binary predicate
- (b) universal theory $T_0 \subseteq \mathbb{L}(\tau_*)$ is such that: a τ-model M satisfied T_0 iff
  - (α) $b \mapsto P^M_b$ embeds $\mathbb{B}$ into the Boolean Algebra $\mathscr{P}(P^M_{1_\mathbb{B}})$ so $P^M_{0_\mathbb{B}} = \emptyset$
  - (β) $\langle P^M_{1_\mathbb{B}}\rangle {}^\frown \langle Q^M_\theta : \theta < \kappa\rangle$ are pairwise disjoint
  - (γ) $E^M_{\theta,i}$ is an equivalence relation on Q^M_θ so $aE^M_{\theta,i}b \Rightarrow a,b \in Q^M_\theta$
  - (ε) if $i < j < \theta$ then $E^M_{\theta,j}$ refines $E^M_{\theta,i}$.

So

$\oplus_1$
- (a) $T_0 \subseteq \mathbb{L}(\tau_*)$ is a well defined universal theory
- (b) Mod_{T_0} has amalgamation and the JEP.

Let

$\oplus_2$ $\mathbb{T}$ is the set of $\tau \subseteq \tau_*$ satisfying:

(a) $P, P_{1_{\mathbb{B}}}, P_{0_B} \in \tau$

(b) $E_{\theta,i} \in \tau_1 \Rightarrow Q_\theta \in \tau$

(c) if $\mathbb{B} \models$ "$b \cap c = a \wedge -b = d$" then $\{P_b, P_c\} \subseteq \tau_1 \Rightarrow \{P_a, P_d\} \subseteq \tau$

$\oplus_3$ for $\tau \in \mathbb{T}$ let $T_{0,tau}$ be defined like T_0 but restricting ourselves to predicates from τ_1.

Now

$\oplus_4$ for $\tau \in \mathbb{T}$

(a) if M is a τ-model of $T_{0,\tau}$, <u>then</u> M can be expanded to a τ_*-model of T_0

(b) $T_{0,\tau}$ has the JEP

(c) $T_{0,\tau}$ has the amalgamation property

(d) if $M_1 \subseteq M_2$ are models or $T_{0,\tau}$ and $\tau \subseteq \tau_1 \in \mathbb{T}$ and N_1 is a τ_1-model expanding M_2 <u>then</u> there is a τ_1-model N_2 expanding M_2 and extending N_1.

[Why? Easy, e.g. clause (b) by disjoint union.]

$\oplus_5$ For finite $tau \in \mathbb{T}, T_{0,\tau}$ has a model completion called $T_{1,\tau}$ which has elimination of quantifiers.

[Why? Because τ is a relational finite vocabulary and $T_{0,\tau}$ is univesal with JEP and amalgamation.]

$\oplus_6$ If $\tau_1 \subseteq \tau_2$ are from $\mathbb{T}$ <u>then</u> $T_{1,\tau_1} \subseteq T_{1,\tau}$.

[Why? By $\oplus_4(d) + \oplus_5$.]

$\oplus_7$ $T_1 := \cup\{T_{1,\tau} : \tau \in \mathbb{T} \text{ finite}\}$ is the model completion of T_0 and has elimination of quantifiers.

[Why? Follows from the above.]

$\oplus_8$

(a) If $\tau \in \mathbb{T}$ is finite, <u>then</u> $T_{1,\tau}$ is $\aleph_0$-categorical and $\aleph_0$-stable

(b) T_1 is stable

(c) $\kappa(T_1) = \kappa$

(d) $|\mathbf{F}(T)| = |\mathbb{B}| + \aleph_0$

(e) $\lambda(T) = \lambda$.

[Why? Consider the monster $\mathfrak{C} = \mathfrak{C}_{T_{1,\tau}}$ and use automorphisms.]
2) We use T_0 such that $(*)'_2$ below holds and continue as above.

$(*)'_2$ as in $(*)'_1$ above but

(a) we add $Q_0, E_{0,n}(n < \omega)$ wih Q_0 unary and $E_{0,n}$ binary

(b)

(β) also Q_0^M is disjoint to them

(ζ) $E^M_{0,n}$ is an equivalence relation on P^M_0

(η) $E^M_{0,0}$ has one equivalence class

(θ) $E^M_{0,n+1}$ refines $E^M_{0,n}$ and divides each $E^M_{0,n}$ equivalence classes to at most 2.

$\square_{1.10}$

{b16}

Discussion 1.11. We like to translate "$M \models$ "$\psi, \psi \in \mathbb{L}_{\lambda^+,\kappa}$" to $M \in \mathrm{Mod}_{\mathbf{t}}$, that is, when $\kappa > \aleph_0$ and $\kappa(T) \geq \kappa$. However, the following is the "translation of $\psi \in \mathbb{L}_{\lambda^+,\kappa}(\tau_0)$"; i.e. it deals strictly with the logic $\mathbb{L}_{\lambda^+,\kappa}$; in particular a Boolean
{b24} Algebra $\mathbb{B}$ is not present. Our aim is to do some of the work of 1.14 in which we
{b20} are really interested. So 1.12 is not directly related to $\mathbf{t}$'s! as there is no saturation
{b24} requirement; moreover stability appears neither in 1.12 nor in 1.14.

{b20} Note that in 1.12 we can let κ_1 be such that $\kappa = \kappa_1^+$ or $\kappa_1 = \kappa$ is a limit cardinal and let $\Upsilon = \kappa_1 + 1$ and omit $F_{\kappa_1}, P_{\kappa_1}$.

{b20}

Theorem 1.12. <u>*The $\mathbb{L}_{\lambda^+,\kappa}$-representation Theorem*</u>

Assume $\psi \in \mathbb{L}_{\lambda^+,\kappa}(\tau_0)$, so of course, $|\tau_0| \leq \lambda$. Let Υ be κ if $\kappa \leq \lambda$ and $\lambda + 1$ if $\kappa = \lambda^+$.

<u>*Then*</u> *we can find a tuple $(\tau_1, T_1, p(x), \bar{F}, \bar{P})$ such that (for $\bar{F}, \bar{P}$ as below):*

(A) (a) *τ_1 is a vocabulary $\supseteq \tau_0$ of cardinality λ*

(b) *$\bar{F}$ is a sequence of unary function symbols with no repetitions of length Υ, new (i.e. from $\tau_1 \backslash \tau_0$), let $\bar{F} = \langle F_i : i < \Upsilon \rangle$*

(c) *$\bar{P}$ is a sequence of unary predicates with no repetitions of length Υ, new (i.e. from $\tau_1 \backslash \tau_0$), let $\bar{P} = \langle P_i : i < \Upsilon \rangle$*

(d) *T_1 is a first order theory in the vocabulary τ_1*

(e) *$p(x)$ is $\{P_*(x) \wedge x \neq c_i : i < \lambda\}$, a $\mathbb{L}(\tau_1)$-type (even quantifier-free), so P_* is a unary predicate and c_i for $i < \lambda$ individual constants*

(B) *the following conditions on a τ_0-model M_0 are equivalent*

(a) *$M_0 \models \psi$ and $\|M_0\| = \|M_0\|^{<\kappa} + \lambda$*

(b) *there is a τ_1-expansion M_1 of M_0 to a model of T_1 omitting $p(x)$ such that:*

(α) *$\langle P_i^{M_1} : i < \Upsilon \rangle$ is a partition of $|M_1|$*

(β) *if $i < \Upsilon$ and $a_j \in M_1$ for $j < i$ then for some $b \in P_i^{M_1}$ we have $j < i \Rightarrow F_j^{M_1}(b) = a_j$.*

Proof. Note that as ψ has no free variables, without loss of generality every subformula of ψ has a set of free variables equal to $\{x_i : i < \varepsilon\}$ for some $\varepsilon < \kappa$.

Let Δ be the set of subformulas of ψ so without loss of generality (a syntactial rewriting) there is a list $\langle \varphi_i(\bar{x}_{[\varepsilon(i)]}) : i < i(*)\rangle$ for some $i(*) \leq \lambda$ of Δ such that $\varepsilon(0) = 0, \varphi_0 = \psi$ and $\bar{x}_{[\varepsilon(i)]}$ is a sequence of length $< \kappa$ of variables, in fact, $\bar{x}_{[\varepsilon(i)]} = \langle x_\varepsilon : \varepsilon < \varepsilon(i)\rangle$ and $\varepsilon(i) < \kappa$.

For any τ_0-model M such that $\|M\| = \|M\|^{<\kappa} + \lambda$ we say N codes M when:

($*$) (a) N expands M

(b) $\langle F_i^N : i < \Upsilon\rangle, \langle P_i^N : i < \Upsilon\rangle$ satisfies $(B)(b)(\alpha), (\beta)$ of the theorem (with N instead of M_1)

(c) $Q_i^N = \{b \in P^N_{\varepsilon(i)} : M \models \varphi_i[\langle F_\varepsilon(b) : \varepsilon < \varepsilon(i)\rangle]\}$ for $i < i(*)$

d) $\langle c_i^N : i < \lambda\rangle$ are pairwise distinct and $P_*^N = \{c_i^N : i < \lambda\}$

(e) $\varphi_i(\bar{x}_{\varepsilon(i)}) = \bigwedge\limits_{j<j(i)} \varphi_{i,j}(\bar{x}_{\varepsilon(i)})$ so $\varphi_{i,j}(\bar{x}_{\varepsilon(i)}) = \varphi_{\mathbf{i}(i,j)}(\bar{x}_{\varepsilon(\mathbf{i}(i,j))})$ and so $\varepsilon(\mathbf{i}(i,j)) = \varepsilon(i)$ <u>then</u> $F_{1,i} \in \tau(N)$ is unary and for $b \in P^N_{\varepsilon(i)}$ we have:

(α) $N \models$ "$F_{1,i}(b) = c_j \wedge \neg\varphi_i(\langle F_\varepsilon(b) : \varepsilon < \varepsilon(i)\rangle)$" implies $M \models \neg\varphi_{i,j}(\langle F_\varepsilon(b) : \varepsilon < \varepsilon(i)\rangle)$ which means: if $\varphi_{i,j} = \varphi_{\mathbf{i}(i,j)}$ and $N \models$ "$\neg Q_i(b) \wedge c_j = F_{1,i}(b)$" then $M \models$ "$\neg Q_{\mathbf{i}(i,j)}[b]$" and, of course

(β) if $M \models \varphi_i(\langle f_\varepsilon(b) : \varepsilon < \varepsilon(i)\rangle)$ and $j < \varepsilon(i)$ then $M \models \varphi_{i,j}(\langle F_\varepsilon(b) : \varepsilon < \varepsilon(i)\rangle)$

(f) if $\varphi_i(\bar{x}_{\varepsilon(i)}) = (\exists \bar{x}_{[\varepsilon(i),\zeta(i))})\varphi_{j_1(i)}(\bar{x}_{\varepsilon(i)}, \bar{x}_{[\varepsilon(i),\zeta(i))})$ and $F_\varepsilon(b) = a_\varepsilon$ for $\varepsilon < \varepsilon(i)$ <u>then</u> (α) $\Leftrightarrow$ (β) where

(α) $M_1 \models \varphi_i[\langle a_\varepsilon : \varepsilon < \varepsilon(i)\rangle]$ equivalently $M_1 \models \varphi_1[\langle F_\varepsilon(b) : \varepsilon < \varepsilon(i)\rangle]$

(β) $M_1 \models (\exists y)\varphi_{j_1(i)}(\langle a_\varepsilon : \varepsilon < \varepsilon(i)\rangle, \langle F_\zeta(y) : \zeta \in [\varepsilon(i), \zeta(i)]\rangle$.

Now let

$\boxplus$ (a) τ_1 is $\tau_\psi \cup \{F_\varepsilon, P_\varepsilon : \varepsilon < \Upsilon\} \cup \{Q_i : i < i(*)\} \cup \{F_{1,i} : i < i(*)$ and φ_i is a conjunction$\}$

(b) $T_1 = \cap\{\mathrm{Th}(N)$: there is M, a τ_0-model of ψ such that $\|M\| = \|M\|^{<\kappa} + \lambda$ and N code $M\}$ <u>or</u> write explicitly all that is used

(c) $p(x) = \{P_*(x) \wedge x \neq c_i : i < \lambda\}$.

Now check that

$\oplus$ $(\tau_1, T_1, p(x), \bar{F}, \bar{P})$ is as required.

$\square_{1.12}$ {b21g}

Remark 1.13. So how does 1.12 help for our main aim? It starts to translate $\psi \in \mathbb{L}_{\lambda^+,\kappa}(\tau_0)$ to $\mathbf{t} = (\tau_1, T_1, p(x))$, so instead having blocks of quantifiers $(\exists \bar{x}_{[\varepsilon]}), \varepsilon < \kappa$ we have $(\exists x)$, i.e. by the sequence of functions $\langle F_i : i < \varepsilon\rangle$ we code any ε-tuple by one element. {b20}

This will help later to make "the $\tau(T_\mathbf{t})$-reduct is saturated" equivalent to the coding.

Recalling Definition 1.5(6) of $\mathbb{L}_{\lambda^+,\kappa}[\mathbb{B}]$, we get the section main result: translating from $\psi \in \mathbb{L}_{\lambda^+,\kappa}[\mathbb{B}]$ to a representation, naturally more complicated than the one for $\psi \in \mathbb{L}_{\lambda^+,\aleph_0}$. {b4}

{b24}

Theorem 1.14. <u>*The $\mathbb{L}_{\lambda^+,\kappa}[\mathbb{B}]$-representation theory*</u>

Assume $\mathbb{B}$ is a Boolean Algebra of cardinality $\leq \lambda$. <u>Then</u> the conclusion of the theorem 1.12 holds using $\psi \in \mathbb{L}_{\lambda^+,\kappa}[\mathbb{B}], \mathrm{Mod}^2_\psi[\mathbb{B}]$ instead $\psi \in \mathbb{L}_{\lambda^+,\kappa}, \mathrm{Mod}^{\cdot}_\psi$ but in clause (B)(b) we add: {b20}

(B) (b) (γ) *$c_b(b \in \mathbb{B})$ are individual constants (in $\tau_1 \backslash \tau_0$) with no repetition, $P, Q \in \tau_1$ unary, $R \in \tau_1$ binary*

(δ) $P^{M_1} = \{c_b^{M_1} : b \in \mathbb{B}\}$

(ε) $R^{M_1} \subseteq P^{M_1} \times Q^{M_1}$

(ζ) *for every* $b \in Q^{M_1}$ *the set* $u(b, M_1) := \{c_b \in P^{M_1} : (c_b, b) \in R^{M_1}\}$ *is an ultrafilter of* $\mathbb{B}$

(η) *for every ultrafilter* D *of the Boolean Algebra* $\mathbb{B}$ *there is one and only one* $b \in Q^{M_1}$ *such that* $u(b, M_1) = D$.

{b20} {b26} *Proof.* Similar to 1.12. $\square_{1.14}$

{b24} *Remark* 1.15. 1) The only non-"$\mathbb{L}_{\lambda^+,\kappa}$ demand" in clause (B) of 1.14 is in $(b)(\eta)$, the existence, this is not expressible by a sentence of $\mathbb{L}_{\lambda^+,\kappa}$, even with extra predicates.
2) As indicated above, $\mathbb{B}^{\rm fr}_\lambda$ is the "worst, most complicated Boolean Algebra" for our purpose. So it is natural to wonder about the order among the relevant Boolean Algebras, so 1.16, 1.17 try to deal with it.

{b40} {b40} **Definition 1.16.** 1) We define a two-place relation $\le^*_{\lambda^+,\kappa}$ among the Boolean Algebras $\mathbb{B}$ of cardinality $\le \lambda$

$\mathbb{B}_1 \le^*_{\lambda^+,\kappa} \mathbb{B}_2$ <u>iff</u>: there is a sentence $\psi_2 \in \mathbb{L}_{\lambda^+,\kappa}[\mathbb{B}_2]$, unary predicates $P_1, Q_1 \in \tau_\psi$ and binary predicate R_2 and individual constants $c^1_b(b \in \mathbb{B}_1)$ from τ_ψ such that:

- if $M \models \psi_2$ then $P^M_1 = \{c^M_b : b \in \mathbb{B}_1\}$ and $R^M_1 \subseteq P^M_1 \times Q^M_1$ satisfies the demands in 1.5(2). {b4}

2) We let $\equiv^*_{\lambda,\kappa}$ be defined by $\mathbb{B}_1 \equiv {}^*\lambda^+, \kappa\mathbb{B}_2$ <u>iff</u> $\mathbb{B}_1 \le^*_{\lambda^+,\kappa} \mathbb{B}_2$ and $\mathbb{B}_2 \le^*_{\lambda^+,\kappa} \mathbb{B}_1$.

{b43} **Claim 1.17.** *1)* $\le^*_{\lambda^+,\kappa}$ *is a quasi-order on the class of Boolean Algebras of cardinality* $\le \lambda$.
2) Hence $\equiv^*_{\lambda,\kappa}$ *is an equivalence relation with being isomorphic refining it.*
{b14} *3) In 1.10(1) we have* $\mathbb{B}_T \equiv^*_{\lambda^+,\kappa} \mathbb{B}$ *where* $T = T^1_{\lambda,\kappa}$.
4) If $\mathbb{B}_1 \le^*_{\lambda,\kappa} \mathbb{B}_2$ <u>*then*</u> *for every* $\psi_1 \in \mathbb{L}_{\lambda^+,\kappa}[\mathbb{B}_1]$ *there is* $\psi_2 \in \mathbb{L}_{\lambda^+,\kappa}[\mathbb{B}_2]$ *such that:*

(a) $\mathrm{spec}^2_{\psi_1} = \mathrm{spec}^2_{\psi_2}$

(b) *if* M_1 *is a* $\tau(\psi_1)$*-model then* $M_1 \in \mathrm{Mod}^2_{\psi_1}$ <u>*iff*</u> $M_1 = M_2{\restriction}\tau_{\psi_1}$ *for some* $M_2 \in \mathrm{Mod}^2_{\psi_2}$*; pedantically we should have an embedding* π *of* τ_{ψ_1} *into* τ_{ψ_2} *and demand* $M_1 = (M_2{\restriction}\mathrm{Rang}(\pi))^{[\pi]}$*, naturally defined.*

5) If $\mathbb{B}$ *is a Boolean Algebra of cardinality* $\le \lambda$ *then* $\mathbb{B} \le^*_{\lambda,\kappa} \mathbb{B}^{\rm fr}_\lambda$.

Proof. Part (2) should be clear and we elaborate part (1).

Let us fix $m \ge 1$ and we shall analyze $\mathbb{B}_{T_1,m}$. Let $\Lambda_1 = \{\eta : \eta$ is a sequence of length m with range included in $\Theta\}$ where $\Theta = \{\theta : \theta < \kappa$ infinite$\} \cup \{0\}$.

For $\theta \in \Theta$ let $\varphi_0(x) = Q_\theta(x)$, interpreting Q_0 as P. Next let $\Lambda_0 = \{\eta{\restriction}u : u \subseteq m$ and $\eta \in \Lambda_1\}$ and for $\eta \in \Lambda_0$ let $\varphi_{\eta,\ell}(\bar{x}_{[m]}) = \bigwedge\limits_{\ell<m} \varphi_{\eta(\ell)}(x_\ell)$ and for $\nu \in \Lambda_0 \backslash \Lambda_1$ let $\Lambda_{0,\nu} = \{\eta \in \Lambda_0 : \nu \subseteq \eta$ and $\mathrm{Rang}(\eta)\backslash\mathrm{Rang}(\nu)$ is a singleton?$\}$.

Lastly

($*$) $\mathbb{B}_{T,m,\eta} = \mathbb{B}_{T,m}{\restriction}\{\bar{a} : a \le \varphi_\eta(\bar{x}_{[m]})/\equiv_T\}$ for $\eta \in \Lambda_0$

($*$) if $\nu \in \Lambda_0\backslash\Lambda_1$, <u>then</u> $\mathbb{B}_{T,m,\nu}$ is the direct sum of $\langle \mathbb{B}_{T,m,\eta} : \eta \in \Lambda_{0,\nu}\rangle$

($*$) $\mathbb{B}_{T,m,\emptyset} = \mathbb{B}_{T,m}$

($*$) if $D \in \mathrm{uf}(\mathbb{B}_{T,m})$ <u>then</u>

- $\bullet_1$ for some $\eta \in \Lambda_0, \varphi_\eta(\bar{x}_{[m]})/\equiv_T \in D$, $|\mathrm{dom}(\eta)|$ minimal
- $\bullet_2$ so D is deteremined by η and $D{\restriction}\mathbb{B}_{T,m,\eta} \in \mathrm{uf}(\mathbb{B}_{T,m,n})$

- $\bullet_3$ if $\eta \in \Lambda$ then η determines D
- $\bullet_4$ if $\mathrm{Rang}(\eta)$ is minimal it is a singleton, so

$(*)$ above if $\mathrm{Rang}(\eta) = \{\theta\}, \theta \geq \aleph_0$ <u>then</u> $\mathbb{B}_{T,m,\eta}$ is isomorphic to $\mathbb{B}_{T^{\mathrm{eq}}_\theta}$, i.e. θ-equivalence relation (see Definition 0.12) {a16}

$(*)$ above if $\mathrm{Rang}(\eta) = \{0\}$, then $\mathbb{B}_{T,m,\eta}$ is isomorphic to the direct sum of $|\{(e,a) : e$ an equivalence relation on $\mathrm{dom}(\eta)\}|$ and a is an e-equivalence class

$(*)$ (a) the number of ultrafilters on $\mathbb{B}_{T,m}$ $(m \geq 0)$ is $|\mathrm{uf}(\mathbb{B})|$ if $|\mathrm{uf}(\mathbb{B})| \geq \lambda$
(b) $|\mathrm{uf}(\mathbb{B}_{T,M})| = \sup\{\theta : \theta < \kappa\} + \aleph_0$.

[Why? Should be clear.]

$(*)$ $\lambda(T) = |\mathrm{uf}(\mathbb{B})| + \sup\{\theta : \theta < \kappa\} + \aleph_0$.

[Why? Easy.]
Also the $\equiv^*_T$ is easy. $\square_{1.17}$

§ 2. Real equality for each T

§ 2(A). **Answering the Original Question and the New One.**

The original question for this work was about the strictly stable case, i.e. fixing $\kappa > \aleph_0$, dealing with $\{\mathbf{t} \in \mathbf{N}_\lambda : \kappa(T_{\mathbf{t}}) = \kappa\}$, so we deal with this case first.

{c2} In this case Theorem 2.1 tells us that for strictly stable T and $\lambda \geq |T|$, the family of classes $\mathrm{Mod}_{\mathbf{t}}$ for $\mathbf{t} \in \mathbf{N}_{\lambda,T}$ and the family of classes $\mathrm{Mod}^2_\psi[\mathbb{B}]$ for $\psi \in \mathbb{L}_{\lambda^+,\kappa}[\mathbb{B}]$ where $\kappa = \kappa_r(T)$ and $\mathbb{B}$ is the Boolean algebra $\mathbb{B}_T$ are very similar. How this is proved? For one direction, we start with $\mathbf{t} \in N_{\lambda,T}$; so the (essential) non-first order part of the demand $M \in \mathrm{Mod}_{\mathbf{t}}$ is "$M{\restriction}\tau(T_{\mathbf{t}})$ is saturated". At first glance we need (in addition to the first order the omission of a type) to say some things on eliminating $u \in [M]^{<\|M\|}$ and relation on it, (as in [BlSh:958]) but because of T being stable it can be ([Sh:c, Ch.III]) expressed by the equivalence of:

- (a) $M{\restriction}\tau(T_{\mathbf{t}})$ is $\kappa_r(T)$-saturated
- (b) if $\mathbf{I} \subseteq M$ is an infinite indiscernible set in $M{\restriction}\tau(T_{\mathbf{t}}), |\mathbf{I}| = \aleph_0$ then we can find an indiscernible set $\mathbf{J} \supseteq \mathbf{I}$ in $M{\restriction}\tau(T_{\mathbf{t}})$ of cardinality $\|M\|$.

So the use of $\mathbb{L}_{\lambda^+,\kappa}$ where $\kappa = \kappa_r(T)$ is natural. If $2^{|T|} \leq \lambda$ this is obvious but otherwise we have to be more careful. We use the Boolean algebra $\mathbb{B} = \mathbb{B}_T$ and the use of $\psi \in \mathbb{L}_{\lambda^+,\kappa}[\mathbb{B}]$ rather than $\mathbb{L}_{\lambda^+,\kappa}$ to express $M{\restriction}\tau(T_{\mathbf{t}})$ is $\aleph_0$-saturated, so by $\kappa_r(T)$-sequence homogeneity this is enough.

Note that on the one hand $M \in \mathrm{Mod}_{\mathbf{t}} \Rightarrow \|M\| \in \mathbf{C}_T = \{\mu : \mu = \mu^{<\kappa(T)} + \lambda(T)\}$,
{b3} see 1.3 but on the other hand for $\psi \in \mathbb{L}_{\lambda^+,\kappa}[\mathbb{B}], M \models \psi$ does not imply it. Still we know that $\mathrm{spec}^1_\psi = \{\|M\| : M \models \psi\}$ and $\mathrm{spec}^2_\psi = \mathrm{spec}^1_\psi \cap \mathbf{C}_T$ are closed enough,
{b5} see Claim 1.6, in particular 1.6(0). Recall that $\mathbb{B} = \mathbb{B}^{\mathrm{fr}}_\lambda$ is the worst case.

For superstable T (for the case we fix (λ, T)), the case, of e.g. $= \mathrm{Th}({}^\omega 2, E_n)_n, E_n = \{(\eta,\nu) : \eta,\nu \in {}^\omega 2, \eta{\restriction}n = \nu{\restriction}n\}$ makes us work somewhat more.

{c2}

Theorem 2.1. *Assume T is a stable first order complete of cardinality $\leq \lambda$ and $\kappa = \kappa_r(T) = \min\{\theta : \theta$ regular and $\theta \geq \kappa(T)\}$ and $\lambda(T) = \min\{\lambda : T$ stable in $\lambda\}$,*
{b13} *see 0.3(3), and let $\mathbb{B} = \mathbb{B}_T$, see Definition 0.7(3A).*

Assume further that $\kappa(T) > \aleph_0$ (i.e. T is not superstable).

1) Then $\{\mathrm{spec}_{\mathbf{t}} : \mathbf{t} \in \mathbf{N}_{\lambda,T}\} = \{\mathrm{spec}^2_\psi[\mathbb{B}] : \psi \in \mathbb{L}_{\lambda^+,\kappa}[\mathbb{B}]\}$.

2) If $\tau_0 = \tau_T$ and $\psi_0 = \wedge\{\varphi : \varphi \in T\}$ or just $\tau_T \subseteq \tau_0, |\tau_0| \leq \lambda, \psi_0 \in \mathbb{L}_{\lambda^+,\kappa}[\mathbb{B}](\tau_0)$ and $M \in \mathrm{Mod}_{\psi_0}[\mathbb{B}] \Rightarrow M \models T$ then there is $\mathbf{t} \in \mathbf{N}_{\lambda,T}$ such that $\mathrm{spec}^2_{\psi_0}[\mathbb{B}] = \mathrm{spec}_{\mathbf{t}}$.

3) If $\mathbf{t} \in \mathbf{N}_{\lambda,T}$ then for some $\psi_1 \in \mathbb{L}_{\lambda^+,\kappa}[\mathbb{B}](\tau_1), \tau_1 \supseteq \tau(T_2)$ and $\mathrm{spec}^\iota_{\psi_1}[\mathbb{B}] = \mathrm{spec}_{\mathbf{t}}$.

{c4}

Remark 2.2. The proof gives more: that the two contexts have the same PC classes. This section is divided to two subsections each to one direction.

Proof. 1) By parts (2),(3).
2) By §(2C) below.
{d2} 3) By §(2B) below, i.e. by 2.10 noting 2.9. $\square_{2.1}$

{c6}

Conclusion 2.3. *If T is first order complete stable theory, $\kappa = \kappa(T), |T| \leq \lambda$ then $H(\mathbf{N}_{\lambda,T})$ is bigger than $H(\mathbb{L}_{\lambda^+,\kappa})$ but smaller than $H(\mathbb{L}_{(2^\lambda)^+,\kappa})$.*

Proof. First assume T is strictly stable, i.e. $\kappa(T) > \aleph_0$. The "bigger than $H(\mathbb{L}_{\lambda^+,\kappa})$"
{b2} follows by 2.1(2) recalling 1.6(1), the first inequality. The "smaller than $H(\mathbb{L}_{(2^\lambda)^+,\kappa})$"
{b2} follows by 2.1(3) recalling 1.6(1), the second and third inequality. We are left with the case T is superstable, but then we quote [BlSh:992], or see below. $\square_{2.3}$

Now we turn to the general case, first we divide to cases in 2.4, prove that fixing {c10}
λ and $|T|$ all the cases occur in 2.5. Then in each case we give quite a complete {c13}
answer. {c10}

Claim 2.4. *If T is a complete first order theory of cardinality $\leq \lambda$ <u>then</u> the pair (λ, T) satisfies exactly one of the following cases:*

<u>Case A</u>: T is unstable

<u>Case B1</u>: T is strictly stable (i.e. stable not superstable)

<u>Case B2</u>: T superstable and $\lambda(T) \leq \lambda$

<u>Case B3</u>: T superstable $\lambda(T) > \lambda$ but $2^{\aleph_0} \leq \lambda$ hence $(D(T)) = |\mathrm{uf}(\mathbb{B}_T)| = \lambda(T)$

<u>Case B4</u>: T superstable, $\lambda(T) > \lambda, 2^{\aleph_0} > \lambda$ but $|D(T)| > |T|$ hence $\mathbb{B}^{\mathrm{fr}}_{\aleph_0}$ is embeddable into $\mathbb{B}_T$

<u>Case C</u>: T superstable, $\lambda(T) > \lambda, 2^{\aleph_0} > \lambda, |D(T)| \leq |T|$

Proof. Should be clear except the "hence" in Case B3 which holds by [Sh:c, Ch.III,§5], see the proof of 2.5 below (the hence in case B4 is easier). $\square_{2.4}$ {c13} {c13}

Claim 2.5. *1) For any cardinal λ among the pairs $\{(\lambda, T) : T$ complete first order of cardinal $\leq \lambda\}$ all the cases from Claim 2.4 occurs, modulo the restriction on λ.* {c10}
2) Moreover, if $\mathbb{B}$ is a Boolean Algebra of cardinality $\leq \lambda$ <u>then</u> all the cases of Claim 2.4 occur among the pairs $\{(\lambda, T) : T$ first order complete of cardinality $\leq \lambda$ {c10}
and T stable $\Rightarrow \mathbb{B}_T \equiv^*_{\lambda^+,\kappa(T)} \mathbb{B}\}$ again modulo the restriction on λ and on $|\mathrm{uf}(\mathbb{B})|$ (see the proof).

Proof. For case A use T the theory of random graphs.
For the other cases fix $\mathbb{B}$.
For case B1, see claim 1.10, for any $\kappa \in [\aleph_1, \lambda^+]$. {b14}
For case B2, we should assume $|\mathrm{uf}(\mathbb{B})| \leq \lambda$ and we use claim 1.10 for $\kappa = \aleph_0$. {b14}
For case B3, by [Sh:c, Ch.III,§5] we know that $\lambda(T) = |D(T)|$.
For case B4, similarly.
For case C, let $T_0 = \mathrm{Th}({}^\omega 2, E_n)_{n<\omega}, E_n = \{(\eta, \nu) : \eta, \nu \in {}^\omega 2$ and $\eta \restriction n = \nu \restriction n\}$. $\square_{2.5}$ {c17}

Theorem 2.6. *Assume (λ, T) satisfies one of the cases B1-B4 from 2.4.* {c10}
1) $\{\mathrm{spec}_{\mathbf{t}} : \mathbf{t} \in \mathbf{N}_{\lambda,T}\}$ is equal to $\{\mathrm{spec}^2_\psi : \psi \in \mathbb{L}_{\lambda^+,\kappa_r(T)}[\mathbb{B}_T]\}$.
2) $\{H(\mathbf{t}) : \mathbf{t} \in \mathbf{N}_{\lambda,T}\} = \{H(\psi) : \psi \in \mathbb{L}_{\lambda^+,\kappa_r(T)}[\mathbb{B}_T]\}$, see Definition 1.1(3),1.5(5). {b2}
3) $H(\mathbf{N}_{\lambda,T}) = H(\mathbb{L}_{\lambda^+,\kappa_r(T)}[\mathbb{B}_T])$ hence is $\geq H(\mathbb{L}_{\lambda^+,\kappa_r(T)})$ and is $< H(\mathbb{L}_{(2^\lambda)^+,\kappa_r(T)})$.
4) If (λ, T') satisfies one of the cases B1-B4 and for transparency $\kappa_r(T') = \kappa_r(T)$ and $\mathbb{B}_{T'} \leq^*_{\lambda^+,\kappa_r(T)} \mathbb{B}_T$ then $\{\mathrm{spec}_{\mathbf{t}} : \mathbf{t} \in N_{\lambda,T'}\} \subseteq \{\mathrm{spec}^2_{\mathbf{t}} : \mathbf{t} \in N_{\lambda,T}\}$.

Proof. Similar to the proof of Theorem 2.1, except that: for case B1 use Claim {d2}
2.10, for case B2 use Claim 2.11, for Case B3 use claim 2.12(1) and for Case B4 use {d8}
2.12(2). $\square_{2.6}$ {d12}

{d20} {b20}

Theorem 2.7. *If (λ, T) satisfies Case C of 2.4, then the parallel of Theorem 1.14 holds except that we replace $\mathbb{B}_T$ by $\mathbb{B}'_T = \mathbb{B}_t \oplus \mathbb{B}^{\rm fr}_{\aleph_0}$, $\oplus$ is the sum.*

Proof. Similar but we shall elaborate in §(2D). $\square_{2.7}$

{d23}
{c10} **Theorem 2.8.** *Assume (λ, T) satisfies Case A of Claim 2.4 and $\mathbf{C} = \{\mu : \mu = \mu^{<\mu} \geq |D(T)|\}$ is an unbounded class of cardinals. Recall that*

> $(*)$ *if M is a saturated model of T then $\|M\| \in \mathbf{C}$, see* [Sh:c, Ch.III].

Then the results of [BlSh:958] *holds even if we fix T, that is: $\{\mathrm{spec}_{\mathbf{t}} : \mathbf{t} \in \mathbf{N}_{\lambda,T}\} = \{\mathrm{spec}_\psi \cap \mathbf{C} : \psi \in \mathbb{L}^{\rm mse}_{\lambda^+,\lambda^+}\}$ where $\mathbb{L}^{\rm mse}_{\lambda^+,\lambda^+}$ is $\mathbb{L}_{\lambda^+,\lambda^+}$ extended by the quantification over 2-place relations of cardinality (strictly) smaller than that of the model.*

Proof. Of course, the inclusion $\subseteq$ is trivial. For the other inclusion the proof splits to two cases and always at least one of them holds by [Sh:c, Ch.II].

Case 1: T has the independence property

So some $\varphi(x, \bar{y}_n) \in \mathbb{L}(\tau_T)$ has the independence property.

Let $\tau_0 = \tau_T \cup \{P, F_\ell, Q, c_i : i < \lambda, \ell < n\}, Q$ unary, P an n-place predicate, F_ℓ a binary function symbol and c_i an individual constant.

Let T^*_0 be the $\mathbb{L}(\tau_0)$-theory such that:

$(*)$ for a τ_0-model $M, M \models T^*_0$ iff
- (a) $M{\restriction}\tau_T \models T$
- (b) $\{\varphi(x, \bar{a}) : \bar{a} \in P^M\}$ is an independent set of formulas
- (c) the function $(a, b) \Rightarrow \langle F_\ell(a, b) : \ell < n\rangle$ is a one-to-one function from $M \times M$ onto P^M
- (d) $c^M_i \in Q^M$ are pairwise distinct
- (e) $<^M$ is a linear order of (M)
- (f) $<^M$ satisfies the schemes of being well ordered (in fact enough for some specific schemes).

Note

$(*)$ if M is a saturated model of T then it has an expansion M'_0 to a τ^*_0-model of T_0 such that $Q^M = \{c^M_i : i < \lambda\}$.

The rest should be clear being as in the proof of Theorem 2.5, see Claim 3.5, [BlSh:958]; that is, (informally) for suitable $\mathbf{t}$ we are

- guaranteed that in $M \in \mathrm{Mod}_{\mathbf{t}}$ the saturation tells us we can represent enough sets such that together with type omitted we know $<^M$ is a well ordering so can define a subset of order type $\|M\|$ and then can express ψ.

Case 2: T has the strict order property

There are n and $\varphi(\bar{x}_{[n]}, \bar{y}_{[n]}) \in \mathbb{L}(\tau_T)$ which defines a partial order with arbitrarily large finite chains. Let $M \models T$ be $\aleph_1$-saturated so we can find $\bar{a}_k \in {}^n M$ for $k \in \mathbb{N}$ such that $M \models \varphi[\bar{a}_{k(1)}, \bar{a}_{k(2)}]$ iff $k(1) < k(2)$. We expand M to M_0 by an interpretation of number theory, that is:

- $P^M_0 = \{\bar{a}_k : k \in \mathbb{N}\}$

- $F_+^{M_0}$ is the partial function $F_T^{M_0}(\bar{a}_{k(1)}, \bar{a}_{k(2)}) = \bar{a}_{k(1)+k(2)}$
- $F_+^{M_0}$ is the partial function $F_x^M(\bar{a}_{k(1)}, \bar{a}_{k(2)}) = \bar{a}_{k(1)\cdot k(2)}$
- $<^{M_0} = \{\bar{a}_{k(1)}, \bar{a}_{k(2)}) : k(1) < k(2)\}$.

Let M_0' be a model of $\mathrm{Th}(M_0)$ such that $|P_0^{M_0'}| = |M_0'|$, let M_0'' be M_1' expanded by unary function $F_\ell^{M_0''}(\ell < n)$ such that $a \mapsto \langle F_\ell^{M_0'}(a) : \ell < n\rangle$ is a one-to-one function from M_0' onto $P^{M_0'}$.

Lastly, let $T' = \mathrm{Th}(M_0'')$.

Now note that

$(*)$ if N is a model of T' such that $\mathbb{N}_N := (P_0^N, <^N, F_+^N, F_x^N)$ then
 - (a) $\mathbb{N}_N$ is a model of PA
 - (b) if in addition $N{\restriction}\tau_T$ is saturated then $(P_0^N, <^N)$ is an atomically saturated model.

Hence by Malliaris-Shelah [MiSh:1051]

$(*)$ above also $\mathbb{N}_N$ is saturated.

Using $\langle F_\ell : \ell < n\rangle$ we can continue as in Case 1. $\square_{2.8}$

§ 2(B). **Given $\mathbf{t} \in \mathbf{N}_{\lambda,1}$.**

{d2}

Hypothesis 2.9. For this subsection we are given $\mathbf{t} = (T, T_1, p) \in \mathbf{N}_{\lambda,T}$ such that T is complete first order stable so $\lambda \geq |T_1| \geq |T|$ and let $\mathbb{B} = \mathbb{B}_T, \kappa = \kappa_\tau(T)$; without loss of generality:

- (a) $P, Q, R, c_b (b \in \mathbb{B})$ are <u>not</u> in $\tau(T_1)$ and with no repetition
- (b) P, Q are unary predicates, R is a binary predicate, c_b individual constants
- (c) $\tau_2 = \tau(T_1) \cup \{P, Q, R, c_b : b \in \mathbb{B}\}$.

{d4}

Claim 2.10. *Assume $\kappa > \aleph_0$. There is $\psi \in \mathbb{L}_{\lambda^+,\kappa}[\mathbb{B}](\tau_1)$ such that* $\mathrm{Mod}_{\mathbf{t}} = \{N{\restriction}\tau(T_1) : N \models \psi$ *so* $\tau(N) = \tau(\psi) \supseteq \tau_1\}$.

Proof. Note this below proving 2.11, 2.12 we use this proof stating the changes; there $\kappa(T) = \aleph_0$, i.e. T is superstable. {d8}

<u>Stage A</u>:

Without loss of generality we can replace T by T^{eq} (no need for new elements: we can extend T_1 to have a copy of M^{eq} with new predicates and an isomorphism). The use of T^{eq} is anyhow just for transparency. For $\theta = \mathrm{cf}(\theta) < \kappa_r(T)$ choose a sequence $\bar{\varphi}_\theta = \langle \varphi_{\theta,i}(x, \bar{y}_{\theta,i}) : i < \theta\rangle$ witnessing $\theta < \kappa_r(T)$ equivalently $\theta < \kappa(T)$.

<u>Stage B</u>:

Let $\tau = \tau(T_1) \cup \{P, Q, R, S_{\varphi(\bar{x}_{[n]},\bar{y}_{[n]})}, G_n, c_b, Q_\theta, <_\theta, F_i, P_i, F_{1,i} : b \in \mathbb{B}, i < \kappa, \varphi(\bar{x}_n, \bar{y}_n) \in \mathrm{EQ}_T\}$, see Definition 0.3(5) on EQ_T; where the union is without repetitions, P_i, Q_θ unary predicates, c_b individual constant, R binary predicate, $S_{\varphi(\bar{x}_{[n]})}$ an n-place function for $\varphi(\bar{x}_{[n]}) \in \mathbb{L}(\tau_T), F_i$ unary function for $i < \kappa; F_{1,n}$ is an n-place function symbol, G_n an n-place function symbol. {b13}

For awhile fix $M_1 \in \mathrm{Mod}_{\mathbf{t}}$, note that by 0.5 {b18}

$(*)_1$ $\|M_1\| = \|M_1\|^{<\kappa} \geq \lambda(T)$.

Let $M = M_1 {\restriction} \tau(T)$ and let $\mathscr{M}[M_1]$ be the set N of such that (for use in other places in $(*)_2$ we do not use "$\kappa > \aleph_0$"):

$(*)_2$ (a) N is a τ-expansion of M_1

{b24} (b) $P^N, Q^N, R, \langle c_b^N : b \in \mathbb{B}\rangle$ code $\mathbb{B}_T$ and $\mathrm{uf}(\mathbb{B}_T)$, see 0.7(3) and e.g. 1.14$(B)(b)(\gamma) - (\eta)$

(c) (α) $S^N_{\varphi(\bar{x}_{[m]})}(\bar{a}) = \{c_b^N\}$ when $M \models \varphi[\bar{a}]$; essentially this says $b = \varphi_b(x_{[m]})/\equiv_T$ for $b \in \mathbb{B}_{T,m}$

(β) $Q^N = \{d_D : D \in \mathrm{uf}(\mathbb{B}_T)\}$ and $R^N = \{(c_b^N, d_D) : b \in \mathbb{B}$ and $D \in \mathrm{uf}(\mathbb{B}), b \in D\}$

(d) for every $i < \kappa$ and $\bar{a} = \langle a_j : j < i\rangle \in {}^i M$ for some $b \in N$ we have $(\forall j < i)(F_j^N(b) = a_j)$ and $b \in P_i^N$

(e) $\langle P_i^N : i < \lambda\rangle$ is a partition of N

(f) (α) $F_{1,m}^N$ is a function from ${}^m M$ to Q^N such that if $\bar{a} \in {}^m M$ <u>then</u> $d = F_{1,m}^N(\bar{a})$ is the member of Q^N coding $\mathrm{tp}(\bar{a}, \emptyset, M)$, i.e.

- if $D \in \mathrm{uf}(\mathbb{B}_T)$, then we have that $F_{1,m}(\bar{a}) = d_D$ if and only if $\mathrm{tp}(\bar{a}, \emptyset, M) = D$

(β) if $D \in \mathrm{uf}(\mathbb{B}_{T,m})$ then for some $\bar{a} \in {}^m M, F_{1,m}^N(\bar{a}) = d_D$, (recall $\mathbb{B}_{T,m} \subseteq \mathbb{B}_T$)

(g) for any regular $\theta < \kappa_r(T)$ we have:

(α) $Q_\theta^N = \cup\{P_i^N : i \leq \theta\}$ and $(Q_\theta^N, <_\theta^N)$ is a partial order which is a tree with θ levels isomorphic to $({}^{\theta\geq}\|M_1\|, \triangleleft)$ say $\pi_\theta : {}^{\theta>}\|M_1\| \to Q_\theta^N$ is such an isomorphism

(β) let $\bar{a}_\eta^\theta = \langle F_i^N(\pi_\theta(\eta)) : \ell < \ell g(\bar{y}_{\theta,i})\rangle$ for $\eta \in {}^{\theta\geq}\|M_1\|$

(γ) $b_1 <_\theta^N b_2$ <u>iff</u> for some $i_1 < i_2 < \theta$ we have $b_1 \in P_{i_1}^N, b_2 \in P_{i_2}^N$ and $j < \ell_1 \Rightarrow F_j^N(b_1) = F_j^N(b_2)$

(δ) if $i < \theta, \eta \in {}^i\|M_1\|$ and $\alpha < \beta < \|M_1\|$ then $N \models \neg(\exists x)\big((\varphi_{\theta,i}(x, \bar{a}^\theta_{\eta\hat{}\langle\alpha\rangle}) \wedge \varphi_i(x, \bar{a}^\theta_{\eta\hat{}\langle\beta\rangle})\big)$

(ε) if $n < \omega, i_0 < \ldots < i_{n-1} < \theta, \eta_k \in {}^{(i_k)}\|M_\ell\|$ for $k < n$ and $\eta_0 \triangleleft \eta_1 \triangleleft \ldots \eta_{n-1}$ then $N \models (\exists x)(\bigwedge\limits_{k<n} \varphi_{i_k}(x, \bar{a}^\theta_{\eta_k}))$

(ζ) $F_{\theta,j,i}(\pi(\eta)) = \pi(\eta {\restriction} i)$ when $i < j \leq \theta, \eta \in {}^j\|M_1\|$

(θ) for every $c \in Q_\theta^N, F_\theta^N(c)$ is $\pi_\theta(\eta)$ for some $\eta \in {}^{\theta\geq}\|M_1\|$ letting $j_\eta = \ell g(\eta)$ we have

- if $i < j_\eta$ then $N \models \varphi_{\theta,i}[c, \bar{a}^0_{\eta{\restriction}(i_1)}]$
- if $j_\eta < \theta$ then $\alpha < \|M_1\| \Rightarrow N \models \neg\varphi_{J_\eta}[c, \bar{a}_{\eta\hat{}\langle\alpha\rangle}]$

(ι) $F_{\theta,2}^N$ is a binary function such that: if $\eta \in {}^{\theta>}\|M_1\|$ then $\langle F_{\theta,i}^N(c, \pi_\theta(\eta)) : c \in \|M_1\|\rangle$ list with no repetitions $\langle \pi_\theta(\eta\hat{}\langle\alpha\rangle) : \alpha < \|M_1\|\rangle$

(κ) $F_{i,1,\theta}^N$ or $F_{\theta,1}^N$ is a unary function for every $c \in M, F_{1,\theta}(c)$ is

- $\pi(\eta)$ for some $\eta \in {}^{\theta\geq}\|M_1\|$ and for any $i \leq \theta, \nu \in {}^i\|M_1\|$ we have c realize $\{\varphi_j(x, \bar{a}^\theta_{\nu{\restriction}j}) : j < i$ iff $\nu \trianglelefteq \eta\}$

(h) (α) if $j < \kappa$ has cofinality θ, then we have witnesses for clause (d), i.e. if it holds for every $j_1 < j$ then it holds for j; that is, choose $\langle i_j(\iota) : \iota < \theta\rangle$, an increasing with limit j and demand: <u>iff</u> $b_i \in M_2$ for $i < j, d \in N$ and $F^N_{\theta,2}(d) \in P^N_\theta$ and $\iota < \theta \wedge i_* < i_j(\iota) \Rightarrow F^N_{i_*}(F^N_\iota(d)) = b_{i_*}$ <u>then</u> there is $d' \in P_j$ such that $i_* < j \Rightarrow F_{i_*}(d') = b_{i_*}$

(i) (α) if $\kappa > \aleph_0$ and $\langle a_n : n < \omega\rangle$ is an indiscernible set in M <u>then</u> for[3] some $b, a \mapsto G^N_2(a, b)$ is a one-to-one function from M onto an indiscernible set which includes $\{a_n : n < \omega\}$

(β) if $\kappa = \aleph_0, \bar c \in {}^n M, b \in M$ is not algebraic over $\bar c$, then
- $a \mapsto G^N_{n+2}(a, b, \bar c)$ is one-to-one
- $G^N_{n+2}(b, b, \bar c) = \bar b$
- $\{G^N_{n+2}(a, b, \bar c) : a \in M\}$ is an indiscernible set over $\bar c$ based on $\bar c$, all in M.

Let $\psi \in \mathbb{L}_{\lambda^+,\kappa}[\mathbb{B}](\tau)$ be such that:

$(*)_3$ a τ-model N satisfies ψ <u>iff</u>: for a relevant large enough subset Λ of $\mathbb{L}_{\lambda^+,\kappa}[\mathbb{B}](\tau)$ of cardinality $\leq \lambda, \psi = \wedge\{\varphi \in \Lambda$: if $M_1 \in \mathrm{Mod}_{\mathbf{t}}$ and $N \in \mathscr{M}[M_1]$ then $N \models \varphi\}$; we may alternatively demand ψ is such that clauses (a)-(h) below hold:

(a) $N{\restriction}\tau_T$ is a model of T, moreover

(b) $N{\restriction}\tau_{T_1}$ is a model of T_1

(c) $N{\restriction}\tau_{T_1}$ omits p

(d) (e),(f) the parallel of those clauses in $(*)_2$

(g) for every m, every m-type coded by some $a \in \mathbb{B}_{T,m}$ if $b \in P^N_{2i}$ code $\langle a_j : j < 2i\rangle$ satisfies $\langle a_{2j}, a_{2j+1} : j < i\rangle$ is a τ-elementary mapping and $a_{2i} \in N$ then for some $b' \in P_{2i+1}$ and a_{2i+1} the element b' code the τ-elementary mapping $\langle (a_{2j}, a_{2j+1}) : j \leq i\rangle$

(h) recalling $\kappa > \aleph_0$ if $\langle a_n : n < \omega\rangle$ is an indiscernible set <u>then</u> for some $b, a \mapsto G^N_2(a, b)$ is a one-to-one function from N onto an indiscernible set which includes $\{a_n : n < \omega\}$.

Now

$(*)_4$ (a) $\psi \in \mathbb{L}_{\lambda^+,\kappa}[\mathbb{B}]$ indeed

(b) every $M_1 \in \mathrm{Mod}_{\mathbf{t}}$ can be expanded to a model for Mod^*_ψ (see Definition 1.7(2); this is more than being a model of ψ!) {b9}

(c) if $N \in \mathrm{Mod}_\psi$ then $N{\restriction}\tau(T_1) \in \mathrm{Mod}_{\mathbf{t}}$.

[Why? For clause (a) read $(*)_3$. For clause (b) read $(*)_2 + (*)_3$. For clause (c), first why $M_1 = N{\restriction}\tau_{T_1}$ is a model of T_1? Since $M_1 \in \mathrm{Mod}_t$ and $N \in \mathscr{M}[M_1]$, we have that $N \restriction \tau(T_1)$ is a τ-expansion of M_1 by $(*)_2(a)$. Second, why M_1 omit $p_{\mathbf{t}}$? Recalling $(*)_2(f)(\alpha) + (\beta)$ and choice of ψ this should be clear. Third, why is $M = N{\restriction}\tau_T$ saturated? It realizes every $p \in D_m(T) = \mathbf{S}^m(\emptyset, M)$, by $(*)_2(f)$, it is κ-sequence-homogeneous by $(*)_3(g)$ hence is κ-saturated. By $(*)_3(h)$, every

[3]note that when $\kappa > \aleph_0$ we can use G a two-place function symbol

indiscernible subset $\mathbf{I}$ of cardinal $\aleph_0$ can be extended to one of cardinality $\|M\|$. By the last two sentences, M is saturated by [Sh:c, Ch.III].]

So we are done. $\square_{2.10}$

{d8}
{d4} **Claim 2.11.** *Like 2.10, but T is superstable and $\lambda(T) \leq \lambda$.*

Proof. Here the proof "why $M = N{\restriction}\tau_T$ is saturated inside the proof of $(*)_4(c)$ is different. There is a saturated $M_* \in \mathrm{Mod}_T$ of cardinality $\leq \lambda$ and we can demand on ψ that $N \models \psi$ implies M_* is elementarily embeddable into $N{\restriction}\tau_T$ and $N{\restriction}\tau_T$ is $\aleph_0$-sequence homogeneous.

Note that

- $(*)$ if $M_* \prec M \in \mathrm{Mod}_T$ and M is $\aleph_0$-sequence homogeneous implies M is
{b13} $\aleph_\varepsilon$-saturated, see 0.3(0).

{d4} In this case $(*)_2(i)(\beta)$ of the proof of 2.10 implies M is saturated because by [Sh:c, Ch.III]

- $(*)$ M is saturated <u>when</u>: if M is $\aleph_\varepsilon$-saturated and for every finite $A \subseteq M$ and $a \in M \backslash \mathrm{acl}(A)$ there is an indiscernible set $\mathscr{I} \subseteq M$ over A of cardinal $\|M\|$ based on A (i.e. $\mathrm{Av}(M, \mathbf{I})$ does not fork over A) to which a belongs.

$\square_{2.11}$

{d12}
{d4} **Claim 2.12.** *1) Like 2.10 but T is superstable and $2^{\aleph_0} \leq \lambda$.*
{d4} *2) Like 2.10, but T superstable and $|D(T)| > |T|$.*

{d8} *Proof.* As the proof of 2.11 the problem is how ψ guarantees "$N{\restriction}\tau_T$ is $\aleph_\varepsilon$-saturated". As the model is $\aleph_0$-sequence homogeneous it suffices

- $(*)$ for every m and $D \in \mathrm{uf}(\mathbb{B}_{T,m+1})$ equivalently $p \in D_{m+1}(T)$ for some $\bar{a}\hat{\ }\langle c\rangle \in {}^{m+1}N$ realizing p, we have: if $N{\restriction}\tau_T \prec M'$ and $c' \in M'$ realizes $\mathrm{tp}(c, \bar{a}, N{\restriction}\tau_T)$ <u>then</u> some $c'' \in N{\restriction}\tau_T$ realizes $\mathrm{stp}(c', \bar{a}, M')$ in M'.

Let $p = \mathrm{tp}(c, \bar{a}, M)$ and we let $\lambda_* = \lambda(p), \langle E_\alpha(x_0, x_1; \bar{y}_{[m]}) : \alpha < \lambda_*\rangle$, see [Sh:c, Ch.III,5.1,pg.123].

<u>Case 1</u>: $\lambda_* = \aleph_0$

If $2^{\aleph_0} \leq \lambda$ this is easy. If $|D(T)| > |T|$ then for some m there is an independent sequence $\langle \varphi_n(\bar{x}_{[m]}) : n < \omega\rangle$ of formulas of $\mathbb{L}(\tau_T)$ over T; (that is, if $M \in \mathrm{Mod}_T$ then any non-trivial finite Boolean combination of them is realized in M) and we continue as in the second case.

<u>Case 2</u>: $\lambda_* > \aleph_0$

In this case by [Sh:c, Ch.III,5.9,5.10,pg.126] there is a sequence of length λ_* of formulas of the form $\varphi[x, \bar{a}]$ independent in $\mathfrak{C}_T$. Hence there is an independent over T sequence $\langle \varphi_i(x, \bar{y}_{[m]}) : i < \lambda_*\rangle$ of formulas from $\mathbb{L}(\tau_T)$, so $\mathbb{B}^{\mathrm{fr}}_{\lambda_*}$ is embeddable into $\mathbb{B}_{T,m+1}$. So ψ says that the Boolean Algebra $\mathscr{P}(\lambda_*)$ is interpreted in N for every relevant λ_*, but $\lambda_* \leq |T|$.

From this it is easy to have ψ ensuring $(*)$. $\square_{2.12}$

§ 2(C). Coding $\psi \in \mathbb{L}_{\lambda^+,\kappa}[\mathbb{B}_T]$.

{e2}

Hypothesis 2.13.

(a) T is a complete first order theory,
(b) $\lambda \geq |T|, \lambda^+ \geq \kappa$
(c) $\mathbb{B} = \mathbb{B}_T$.

{e4}

Claim 2.14. *Assume $\psi \in \mathbb{L}_{\lambda^+,\kappa}[\mathbb{B}]$ and $\kappa = \kappa_r(T) < \infty$ so T is stable.*
There is $\mathbf{t} = (T, T_1, p) \in \mathbf{N}_{\lambda,T}$ such that $\tau(T_1) \supseteq \tau(\psi)$ and $\mathrm{Mod}_{\mathbf{t}} = \{N \restriction \tau(\psi) : N \in \mathrm{Mod}_\psi[\mathbb{B}]\}$.

Proof. We apply 1.14 to $\mathbb{B}$ and ψ and get $(\tau_1, T_1, p(*), \bar{F}, \bar{P})$ as in 1.12, 1.14 and without loss of generality $\tau_1 \cap \tau(T) = \emptyset$. Now we immitate the proof of 2.10. $\square_{2.14}$ {b20} {d4}

§ 2(D). Elaborating Case C.

In §(2B) we treat most theories T but not all. The remaining case is

{f2}

Hypothesis 2.15.

$\boxplus$ (a) T is superstable of cardinality λ
(b) $\lambda(T) > \lambda$
(c) $2^{\aleph_0} > \lambda$
(d) $\lambda \geq |D(T)|$.

{f6}

Claim 2.16. *There are $m, M \in \mathrm{Mod}_T$ and $\bar{a} \in {}^m M$ such that $\{\mathrm{stp}(c, \bar{a}, M) : c \in M\}$ is of cardinality $2^{\aleph_0}$.*

Proof. Should be clear. $\square_{2.16}$

{f10}

Definition 2.17. For any model M and a sequence $\bar{a}$ from M (or a set $\subseteq$), let $\mathbb{B}_{M,\bar{a},m}$ be the Boolean Algebra of subsets of ${}^m M$ of the form $\varphi(M, \bar{c})$, where $\varphi(\bar{x}_{[m]}, \bar{z}) \in \mathbb{L}(\tau_M), \bar{b} \in {}^{\ell g(\bar{z})} M$ and $\varphi(\bar{x}, \bar{c})$ is almost over $\bar{a}$ which means: for some $\vartheta(\bar{x}_{[m]}, \bar{y}_{[m]}, \bar{z}) \in \mathbb{L}(\tau_M)$ we have:

- in $M, \vartheta(\bar{x}_{[m]}, \bar{y}_{[m]}, \bar{a}) \vdash \varphi(\bar{x}_{[m]}, \bar{c}) \equiv \varphi(\bar{y}_{[m]}, \bar{c})$
- $\vartheta(\bar{x}_{[m]}, \bar{y}_{[m]}, \bar{a})$ defines in M an equivalence relation with finitely many equivalence classes.

{f12}

Claim 2.18. *For T as in 2.15, letting $M, \bar{a}, m$ be as in 2.16 and $\mathbb{B} = \mathbb{B}_{M,\bar{a},m}$ the result of 2.10 and Theorem 2.1 hold if we use $\mathbb{B}$ instead of $\mathbb{B}_T$.* {f8} {d2}

Proof. As above, really $m = 1$ suffice; in particular if $p \in \mathbf{S}(\bar{a}, M), \bar{a} \in {}^m M, M \in \mathrm{Mod}_T$ then $\lambda_*(p) \leq \aleph_0$ (otherwise by Lemma 5.9, 5.10 and 5.11 [Sh:c, Ch.III] we have $|\mathbf{S}^{2m}(\bar{a}, m)| \geq 2^{\lambda_*(p)} > \lambda$, contradiction). $\square_{2.18}$

References

[New12] Ludomir Newelski, *Bounded orbits and strongly generic sets*, J. Lond. Math. Soc. (2) **86** (2012), no. 1, 63–86.

[Sh:c] Saharon Shelah, *Classification theory and the number of nonisomorphic models*, Studies in Logic and the Foundations of Mathematics, vol. 92, North-Holland Publishing Co., Amsterdam, xxxiv+705 pp, 1990.

[Sh:g] ______, *Cardinal Arithmetic*, Oxford Logic Guides, vol. 29, Oxford University Press, 1994.

[BlSh:958] John Baldwin and Saharon Shelah, *A Hanf number for saturation and omission*, Fundamenta Mathematica **213** (2011), 255–270.

[BlSh:992] John T. Baldwin and Saharon Shelah, *A Hanf number for saturation and omission: the superstable case* , Mathematical Logic Quarterly **60** (2014), 437–443.

[MiSh:1051] Maryanthe Malliaris and Saharon Shelah, *Model-theoretic applications of cofinality spectrum problems*, Israel Journal of Mathematics **appeared online**, 67 pps.

Einstein Institute of Mathematics, Edmond J. Safra Campus, Givat Ram, The Hebrew University of Jerusalem, Jerusalem, 91904, Israel, and, Department of Mathematics, Hill Center - Busch Campus, Rutgers, The State University of New Jersey, 110 Frelinghuysen Road, Piscataway, NJ 08854-8019 USA

E-mail address: `shelah@math.huji.ac.il`

URL: `http://shelah.logic.at`