On the way to a new class of efficient chiral dopants for liquid crystalline phases

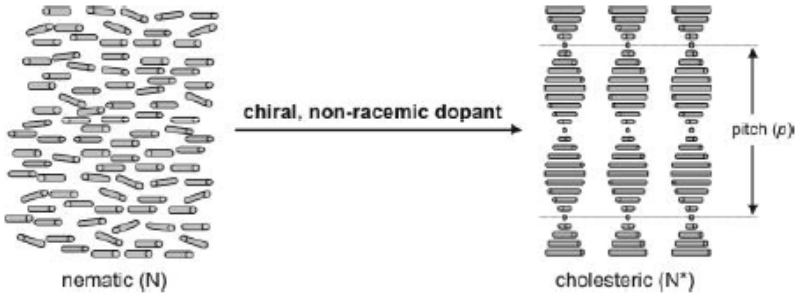
Christian Kühn, November 2014

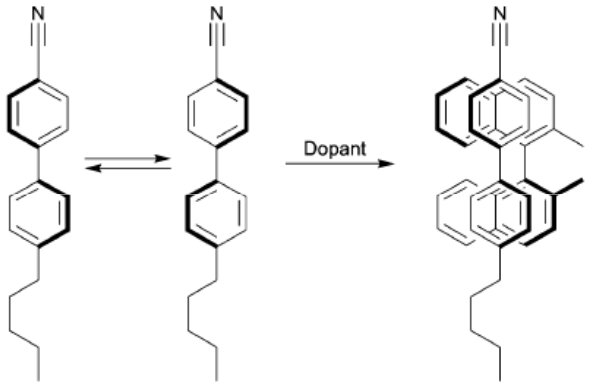
1. Introduction

1.1 Cholesteric Induction

- Elegant method for generation of a cholesteric phase

- Economically attractive concept





- Helical structure

- Cholesteric liquid-crystalline compounds – „smart materials“

M. Braun. *Angew. Chem. Int. Ed.* **2012**, *51*, 2550 – 2562; S. Pieraccini, A. Ferrarini, G. P. Spada. *Chirality* **2008**, *20*, 749 – 759; G. P. Spada, G. Proni. *Enantiomer*. **1998**, *3*, 301 – 314; R. Eelkema, B. L. Feringa. *Org. Biomol. Chem.* **2006**, *4*, 3729 – 3745.

1.2 Helical Twisting Power

- Efficiency of the dopant is quantified by the „helical twisting power“ (HTP or β)

$$\beta = \frac{1}{p \cdot c \cdot r}$$

- HTP values in the range of 100 μm^{-1} are usually considered as „high“
- HTP depends strongly on the nature of the host
- Biaryl derivatives are known to be efficient chiral inducers

S. Pieraccini, A. Ferrarini, G. P. Spada. *Chirality* **2008**, *20*, 749 – 759; G. P. Spada, G. Proni. *Enantiomer*. **1998**, *3*, 301 – 314.

1.3 Dopants

- Requirements: inherently chiral molecules (chiral plane or axis)

  thermal stability

  easily soluble

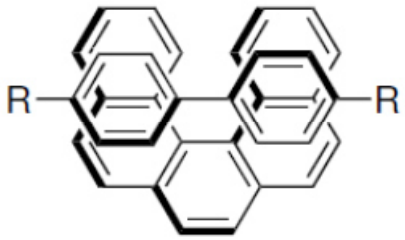
  colorless

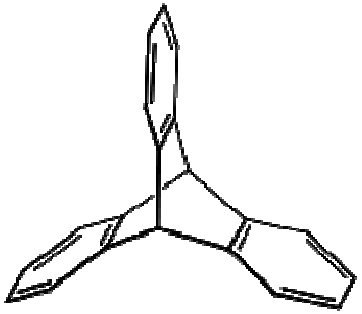
- Good candidates: Binaphthyls, Biphenyls → very well known

  Helicenes (carbo- & heterohelicenes)

  Triptycenes ?

  Triquinacene derivatives ?



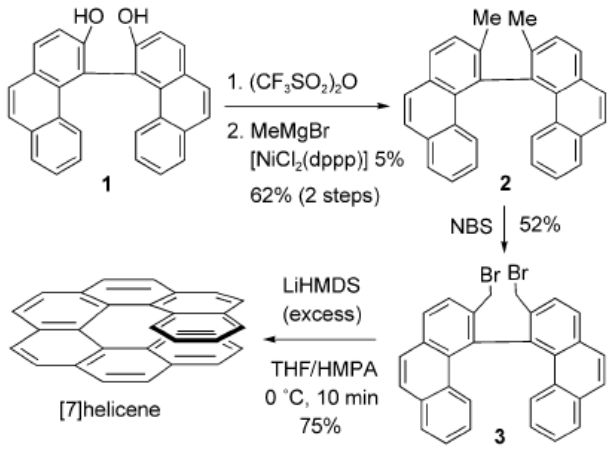


R. Eelkema, B. L. Feringa. *Org. Biomol. Chem.* **2006**, *4*, 3729 – 3745.

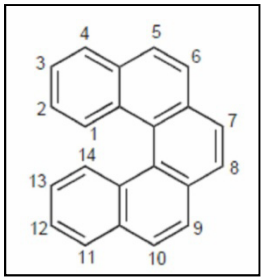
2. Synthesis

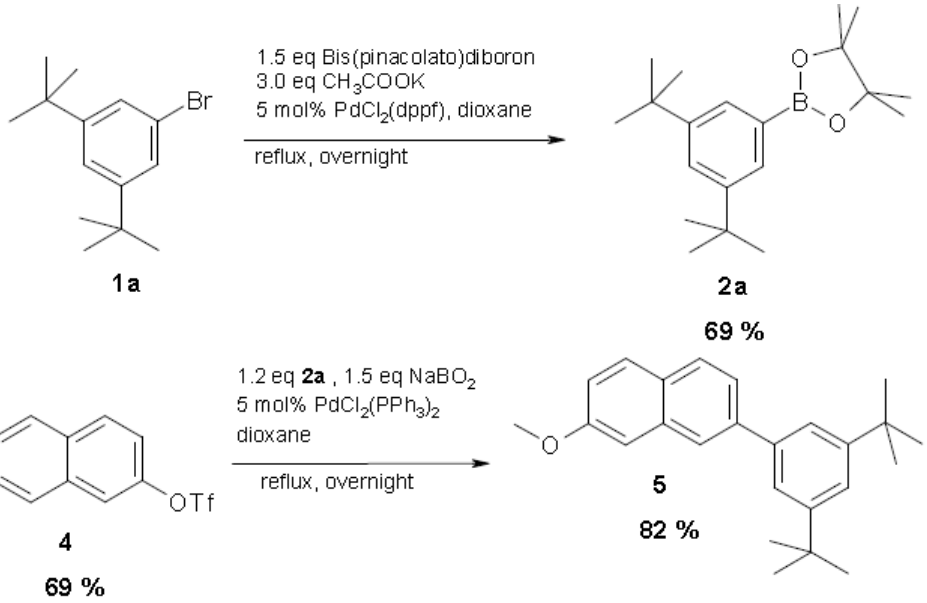
2.1 [5]Helicene derivatives

- Synthesis by carbenoid coupling



- [5]Helicene derivatives need bulky substituents for stable enantiomers





M. Gingras, F. Dubois. *Tetrahedron Lett.* **1999**, *40*, 1309 – 1312.

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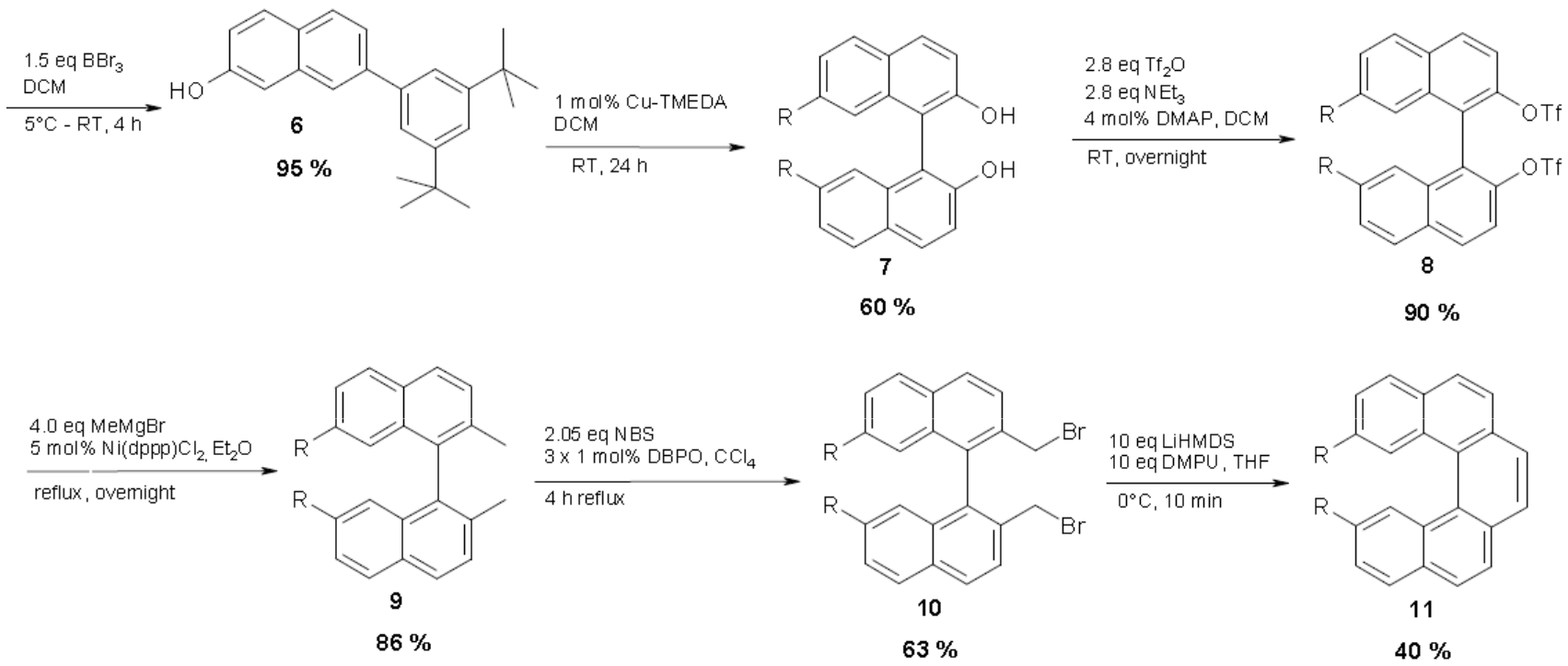
2.1 [5]Helicene derivatives



- Enantiomer separation on a chiral stationary phase

Compound	HTP	Specific rotation α
11	1	2040

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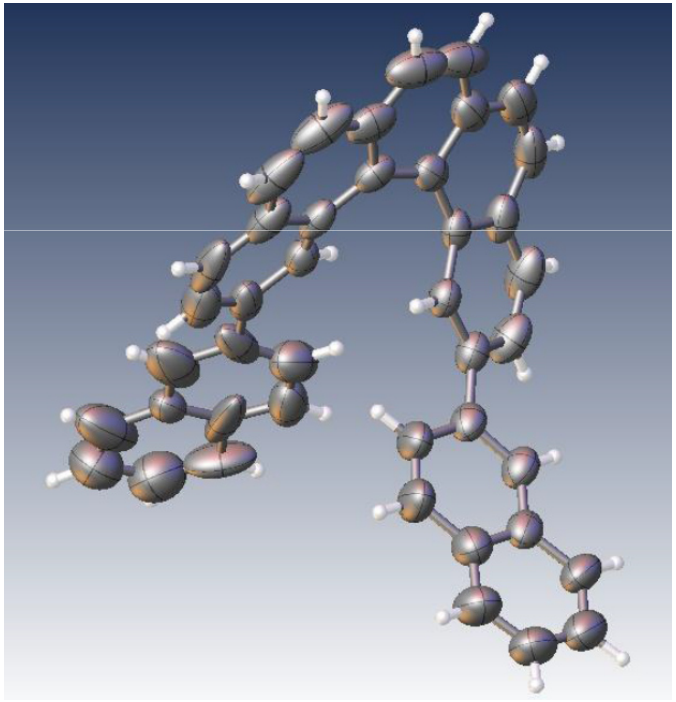
2.1 [5]Helicene derivatives

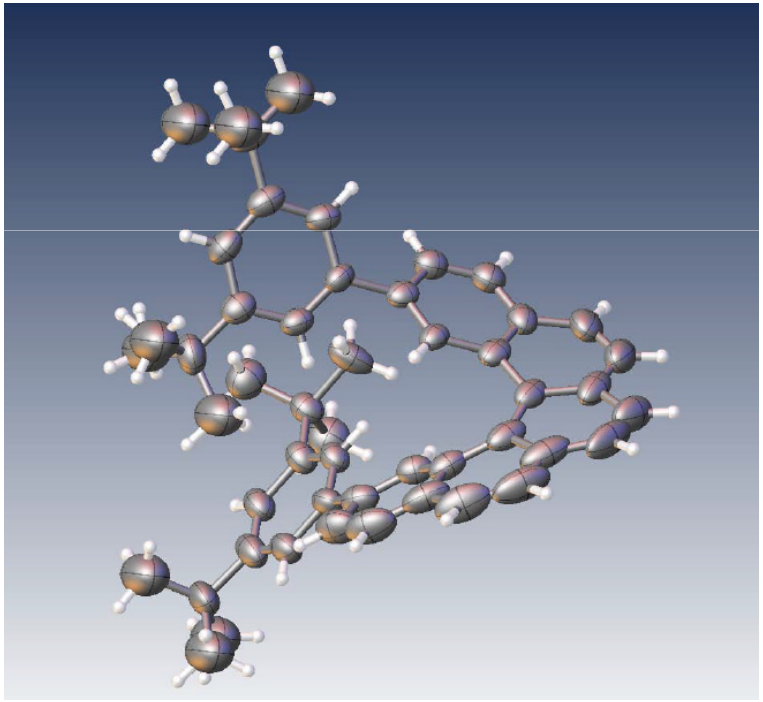
- Comparison of 2,13-substituted [5]Helicenes
- Single crystal structures of:

2,13-Dinaphthyl[5]helicene



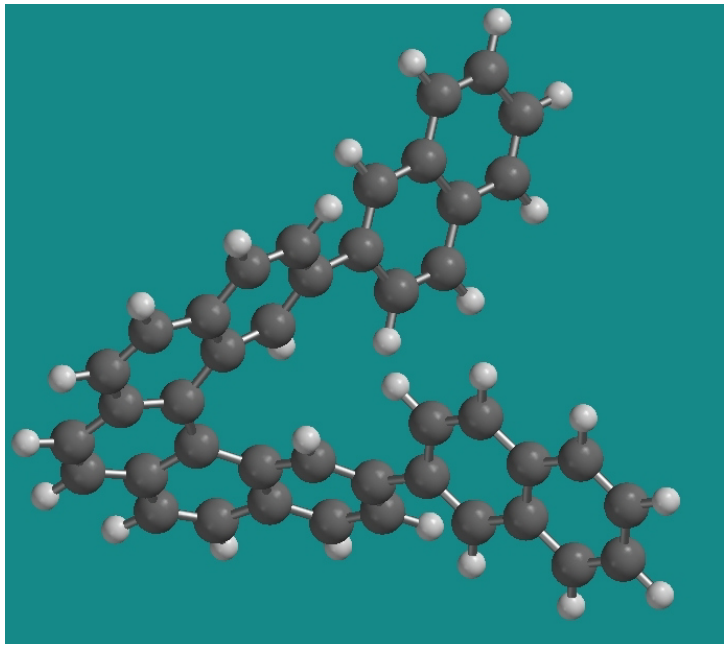
racemize at RT

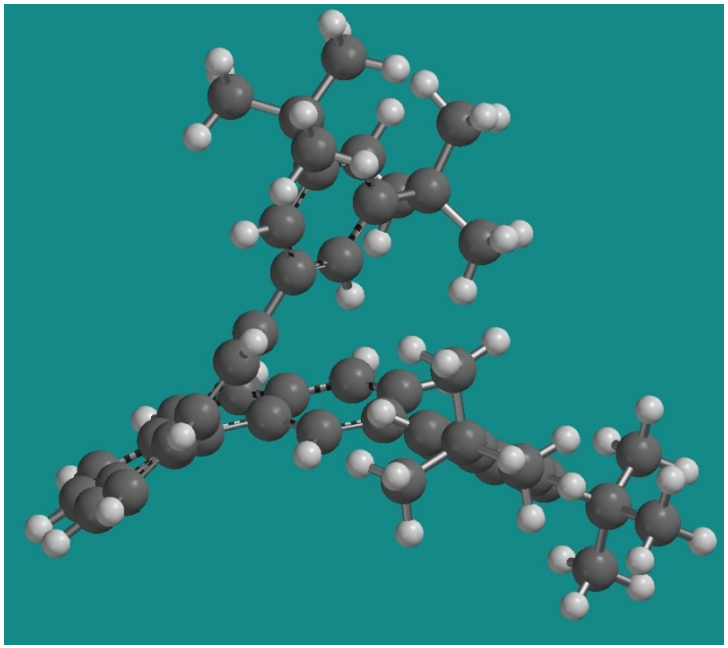
2,13-Bis(di-*tert.*-butylphenyl)[5]helicene



no racemization at 65 °C

2.1 [5]Helicene derivatives



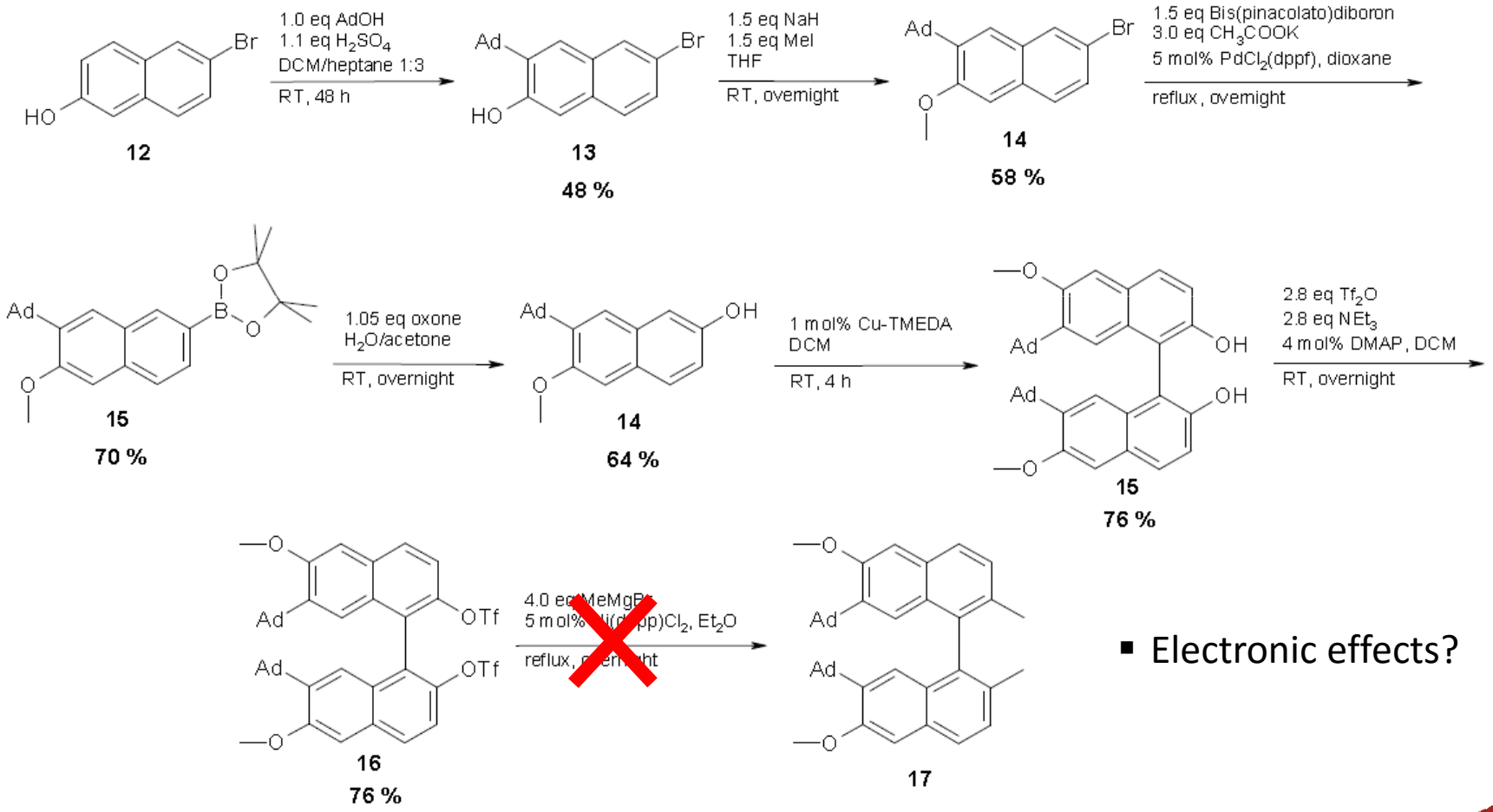


- Structures optimized with B3LYP/6-31G*
- Dihedral angle correlates with racemization barrier

Substituent [5]Helicen	Dihedral angle (th.) [°]	Dihedral angle (exp.) [°]
Naph	30.2	27.4
Ph(*t*-Bu)$_2$	30.9	32.2

2.1 [5]Helicene derivatives

- Bulky substituent → we know!



- Electronic effects?

2.1 [5]Helicene derivatives

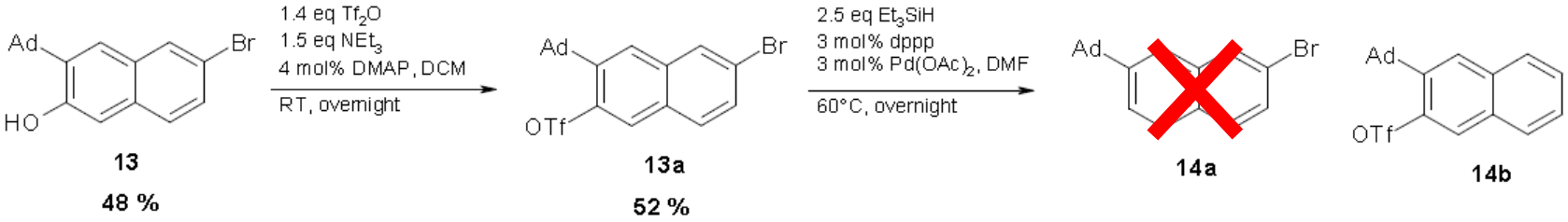
- Various conditions were tested

Solvent	Grignard reagent	Catalyst	T [°C]
Et_2O	MeMgBr	$NiCl_2(dppp)$	35
THF	MeMgBr	$NiCl_2(dppp)$	65
dioxane	MeMgBr	$NiCl_2(dppp)$	100
diglyme	MeMgBr	$NiCl_2(dppp)$	150
THF	MeMgBr	$Pd(dppf)Cl_2$	65
THF	MeZnCl	$Pd(dppf)Cl_2$	65
THF	$MeB(OH)_2$	$Pd(P\text{-}tBu_3)_2$	65
toluene	$MeB(OH)_2$	$Pd(OAc)_2$ + SPhos	110

- No product could be obtained…

2.1 [5]Helicene derivatives

- Palladium-catalyzed reduction of aryl triflates



13 **48 %** **13a** **52 %** **14a** **14b**

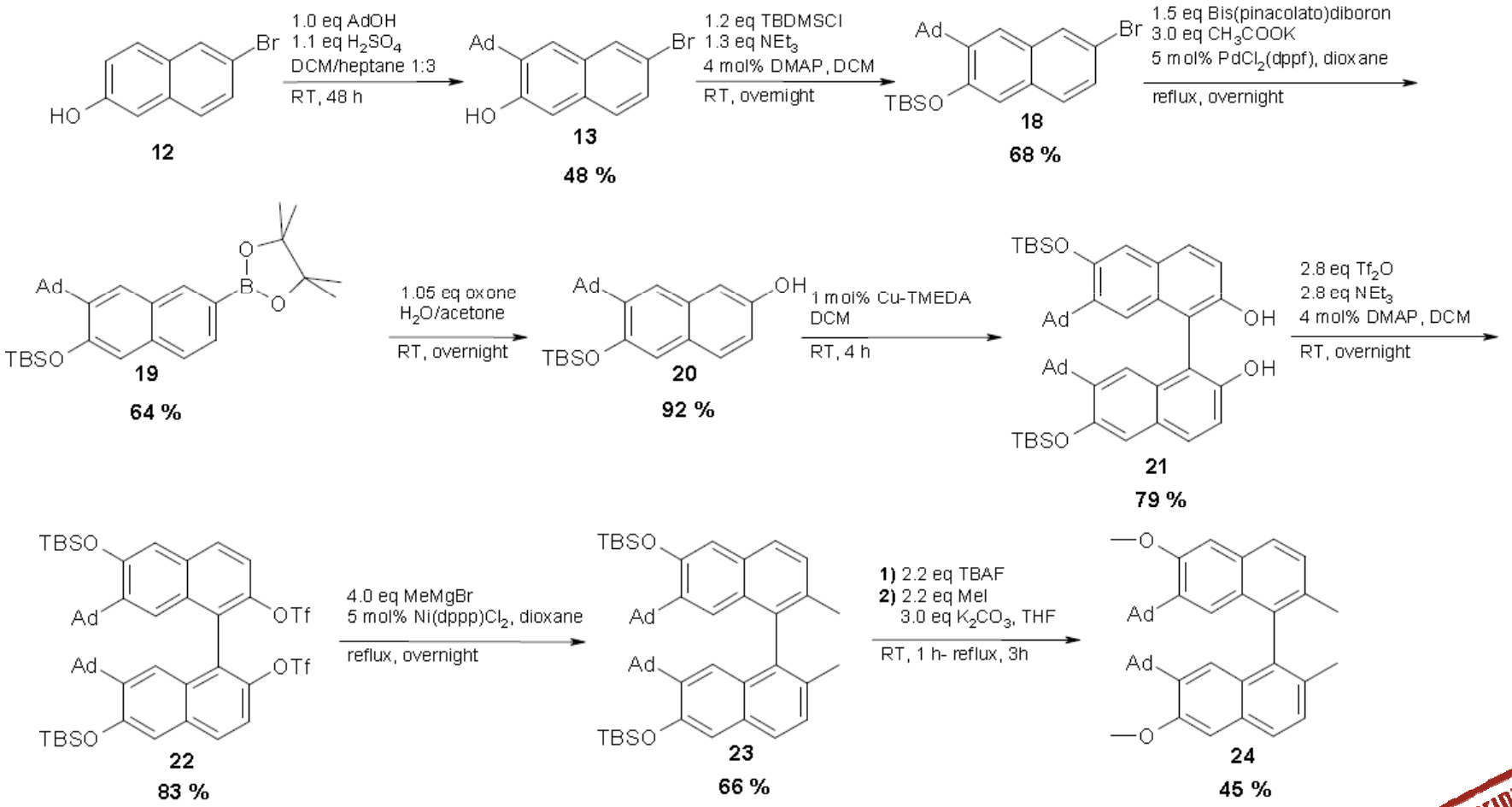
- 2-Naphthyl trifluoromethanesulfonate was reduced successfully under these conditions

- Hydrogenation in the presence of a Pd-catalyst: no selective product

H. Kotsuki, P. K. Datta, H. Hayakawa, H. Suenaga. *Synthesis* **1995**, *11*, 1348 – 1350.

2.1 [5]Helicene derivatives

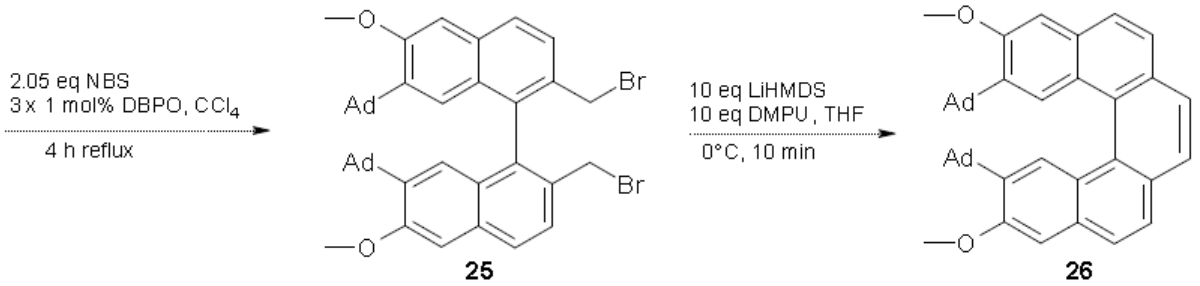
- Synthesis of a derivative without methoxy group

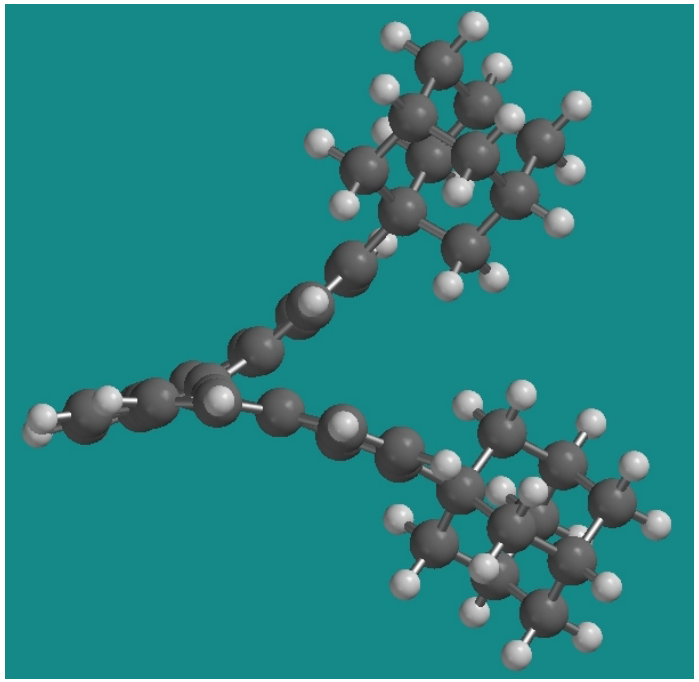


2.1 [5]Helicene derivatives

- 2 steps to complete the synthetic route

- 11-step synthesis to obtain **26**





- Structure optimized with B3LYP/6-31G*
- Dihedral angle: 34.9 °
- **Exp. 33,5!**

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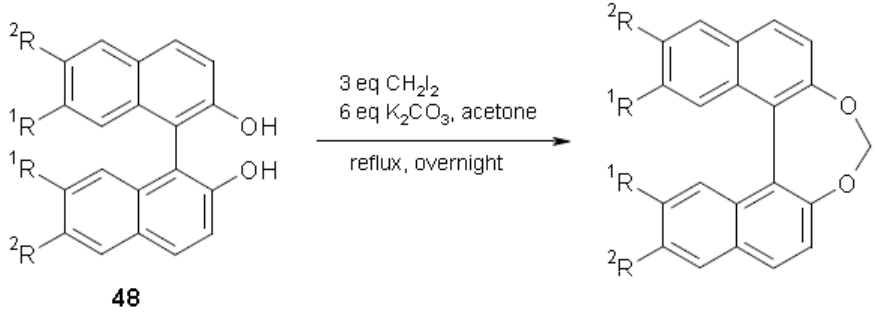
2.2 Bridged Binaphthyls

- Bridged binaphthyls → powerful inducers
- Racemization barriers 5 times higher than [5]helicene



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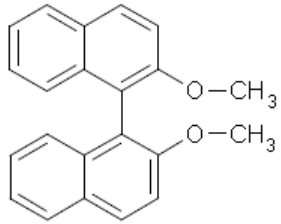


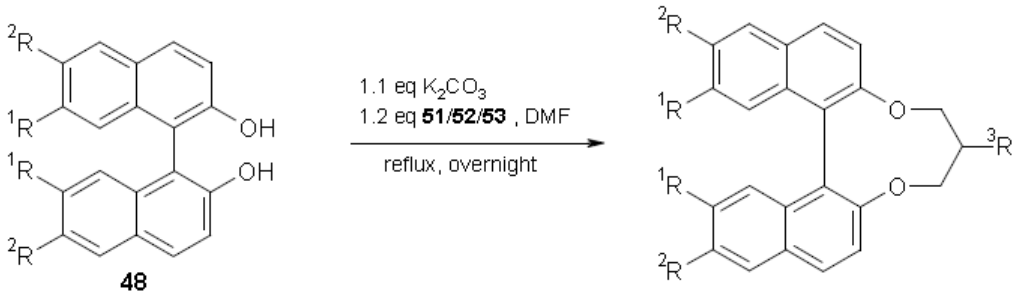
50

1R	2R	Compound	Yield [%]	HTP	Specific rotation α
		50		**4**	93
H	H	49a	79	**41**	783
Naph	H	49b	48	**64**	1325
Ph(*t*-Bu)$_2$	H	49c	58	**3**	937
Ad	OMe	49d	70	**14**	607

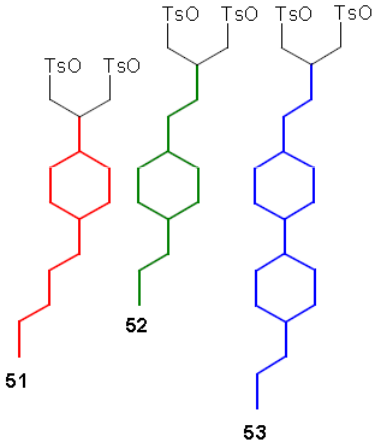
Y. Li, M. Wang, A. Urbas, Q. Li. *J. Mater. Chem. C.* **2013**, *1*, 3917 – 3923. L. Meca, D. Reha, Z. Havlas. *J. Org. Chem.* **2003**, *68*, 5677 – 5680.

2.2 Bridged Binaphthyls

- Bridging with nematic molecules for a better solubility and HTP



	1R	2R	Compound	Yield [%]	HTP	Specific rotation α
3R = 51	**H**	H			**72**	
3R = 51	**Naph**	H	54a	70	**119**	642
3R = 52			54b	45	**103**	640
3R = 53			54c	30	**120**	606
3R = 51	**Ph(*t*-Bu)$_2$**	H	55a	59	**54**	375
3R = 52			55b	47	**47**	397
3R = 53			55c	50	**54**	367
3R = 51	**Ad**	OMe	56a	57	**92**	240
3R = 52			56b	53	**66**	234
3R = 53			56c	49	**78**	189



S. Pieraccini, A. Ferrarini, G. P. Spada. *Chirality* **2008**, *20*, 749 – 759.

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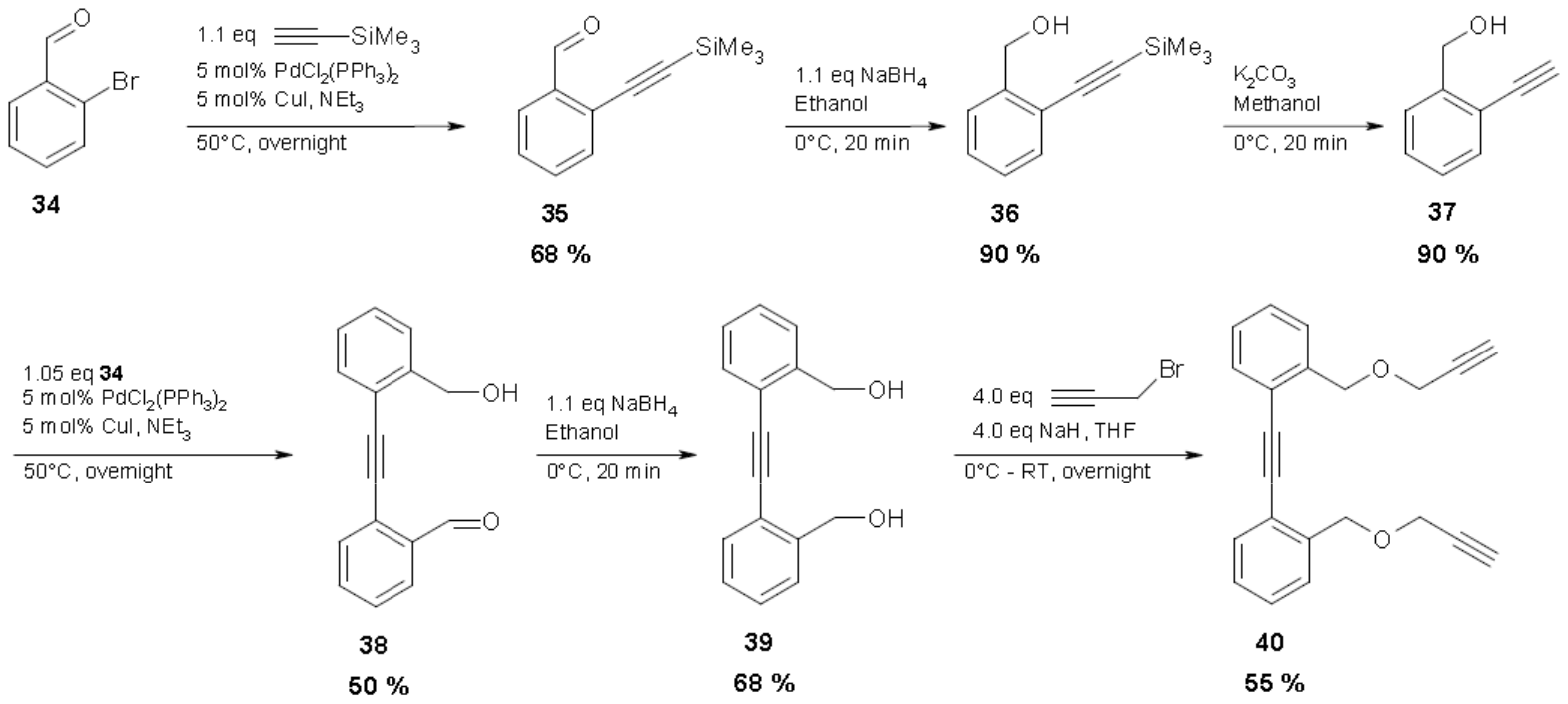
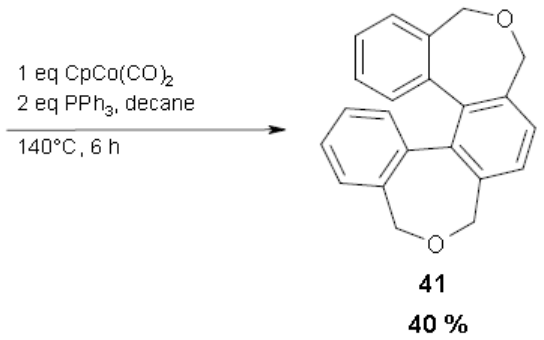
2.3 O-Helicenes



- Synthetic route of functionalized helicenes based on intramolecular [2+2+2] cycloisomerization of triynes

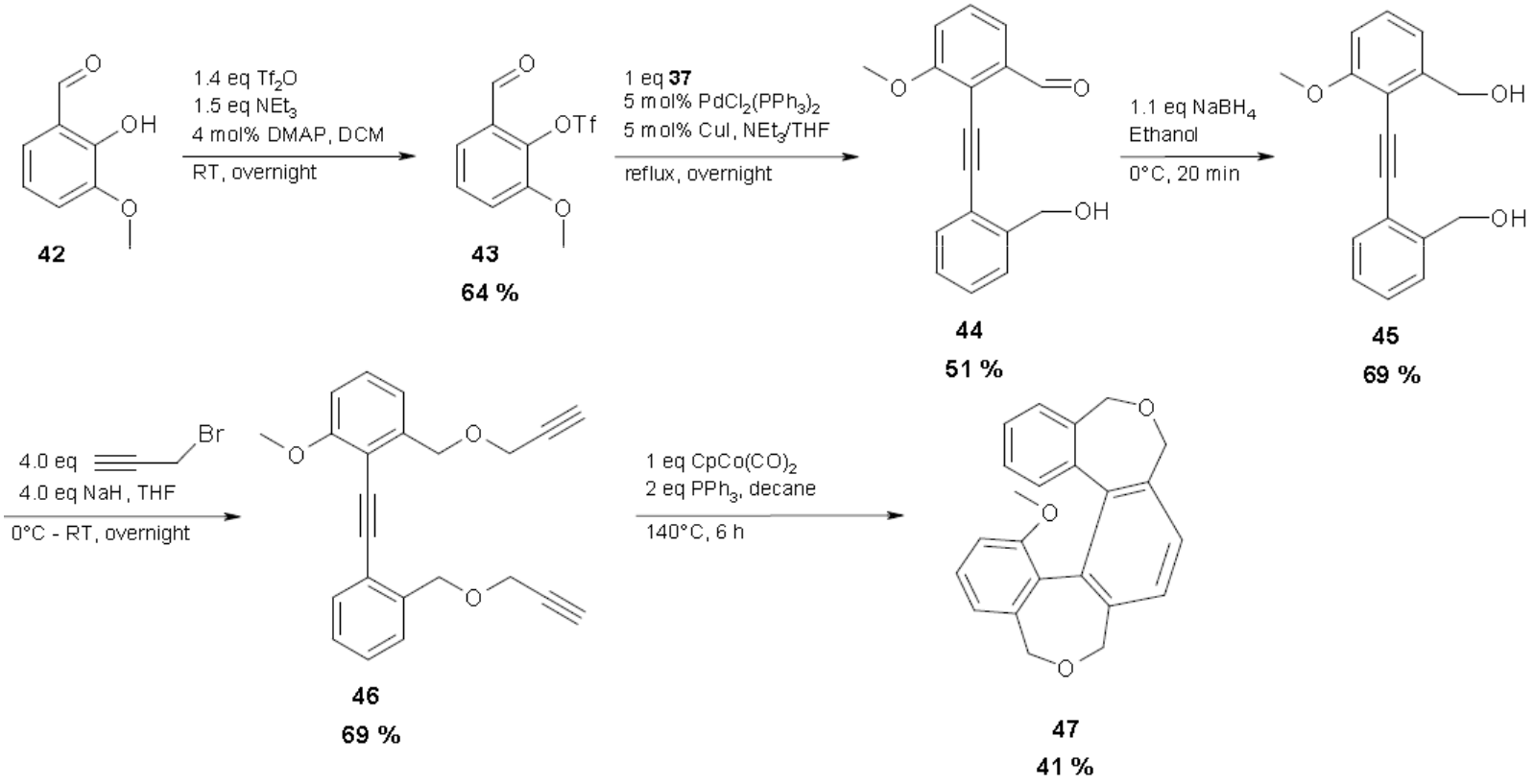


I. G. Stará, I. Starý, A. Kollárovic, F. Teplý, D. Saman, M. Tichý. *J. Org. Chem.* **1998**, *63*, 4046 – 4050.

2.3 O-Helicenes

- Methoxy-substituted derivative
- Stable as single enantiomer

Compound	HTP	Specific rotation α
47	13	88



I. G. Stará, I. Starý, A. Kollárovic, F. Teplý, D. Saman, M. Tichý. *J. Org. Chem.* **1998**, *63*, 4046 – 4050.

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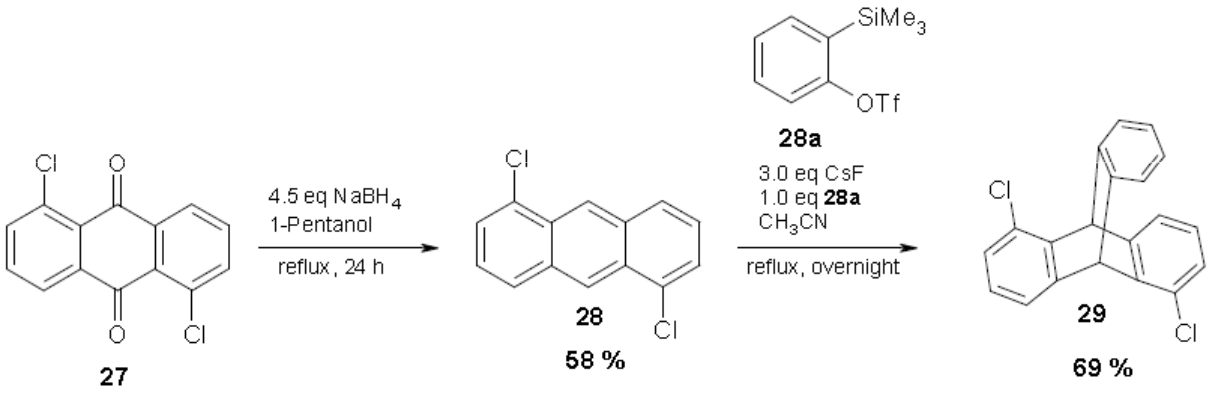
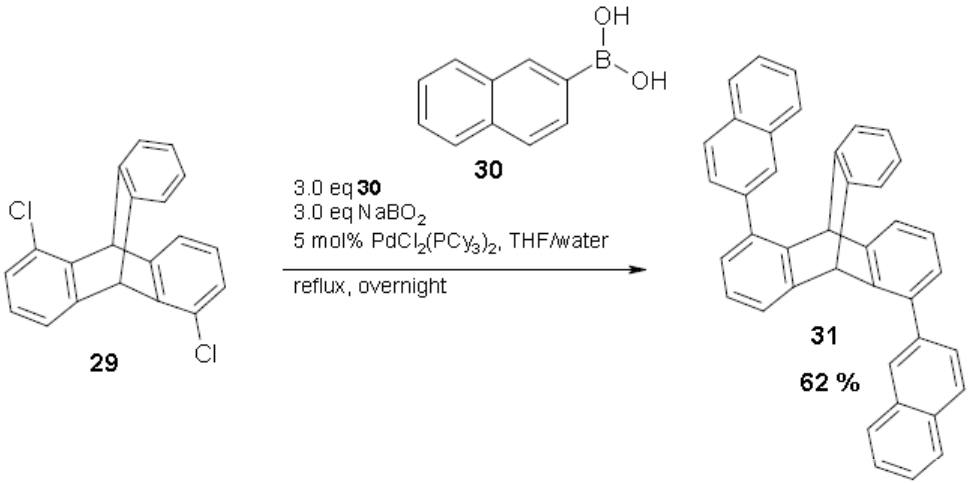
2.4 Triptycenes

- 1,5-substituted
- C_2-symmetrical molecules with a promising structure
- Not investigated as chiral dopants in liquid crystalline phases



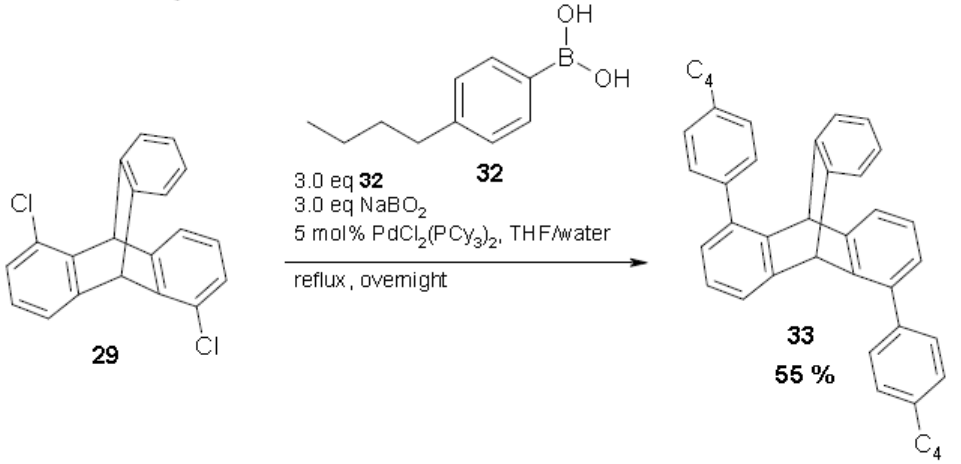
S. M. Bronner, K. B. Bahnck, N. K. Garg. *Org. Lett.* **2009**, *11*, 1007 – 1010; S. J. Ferrara, J. T. Mague, J. P. Donahue. *Inorg. Chem.* **2012**, *51*, 6567 – 6576.

2.4 Triptycenes



- Suzuki reactions between enantiopure **29** and aryl boronic acids to obtain aryl-substituted 1,5-Triptycenes
- PCy_3 very effective ligand for activation of the aryl chlorides

Compound	HTP	Specific rotation α
31	5	50
33	6	32

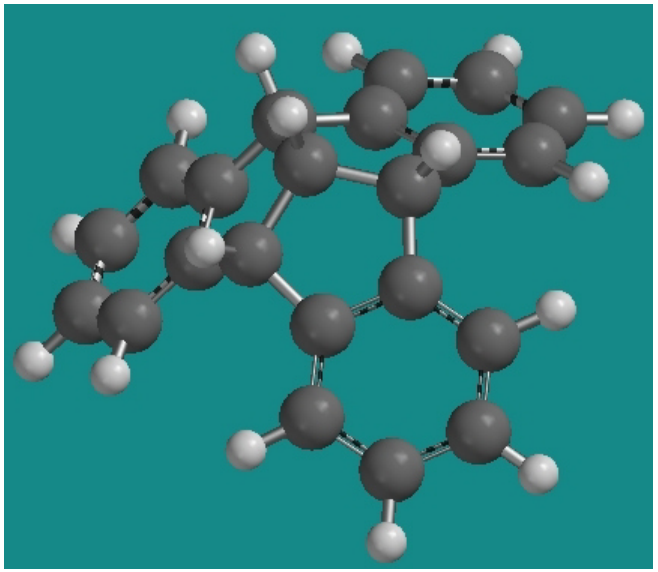


W. Shen. *Tetrahedron. Lett.* **1997**, *38*, 5575 – 5578.

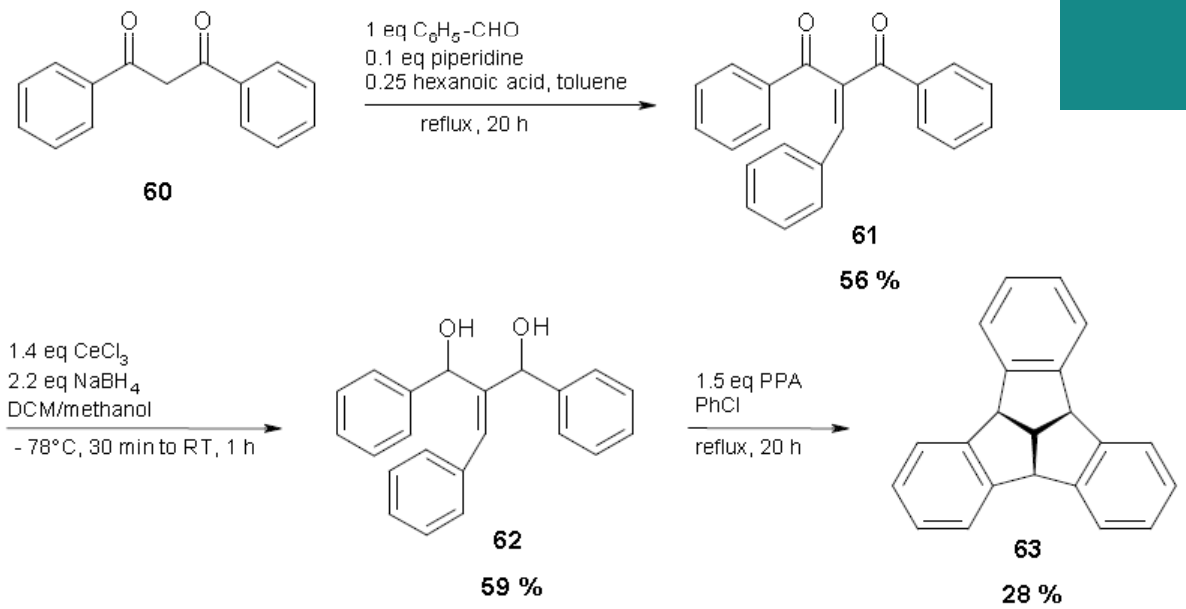
2.5 Triquinacene derivatives

- Tribenzotriquinacene

→ platform for C_3-chiral molecules



- Molecular bowl

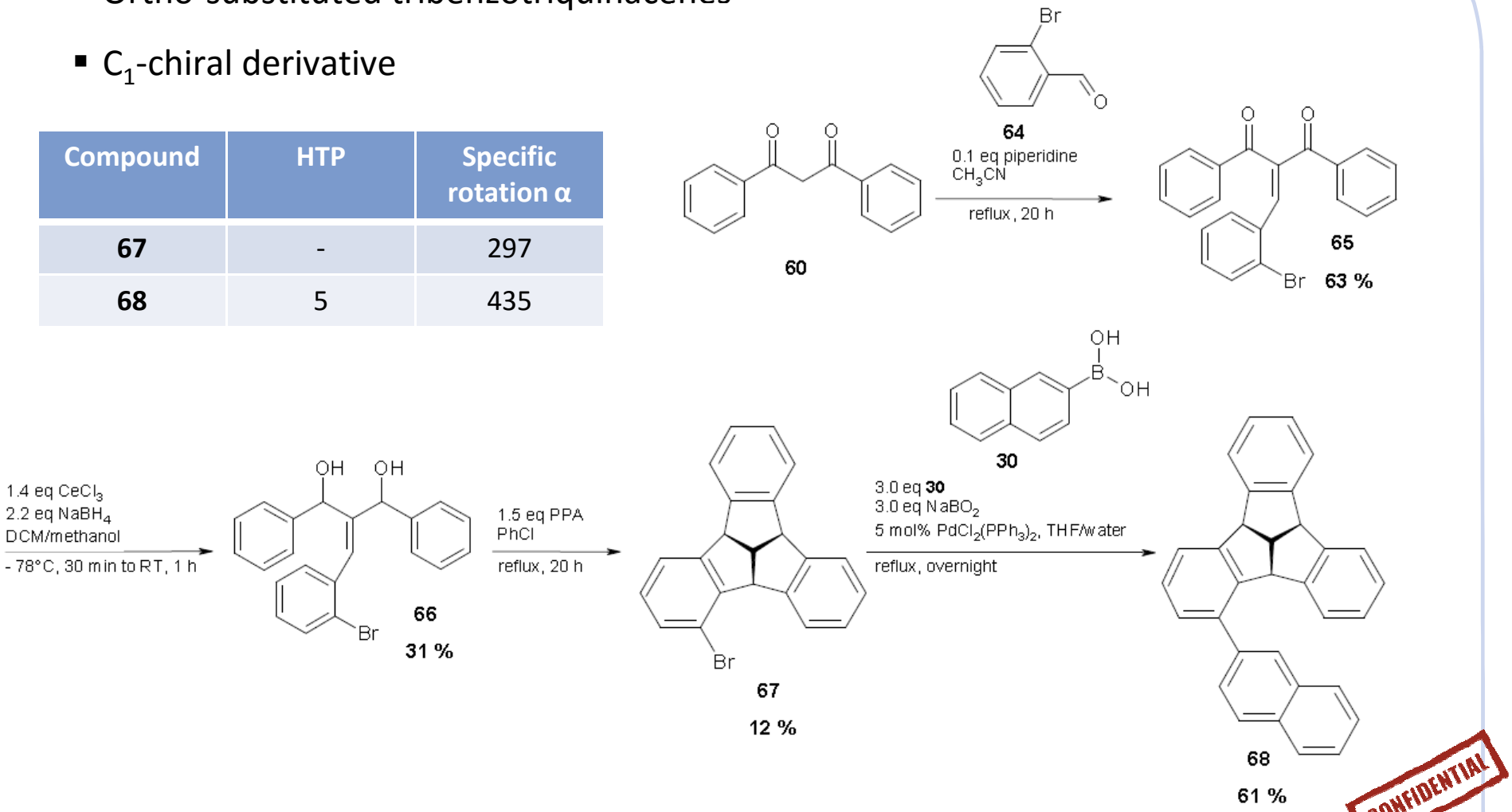


G. Markopoulos, L. Henneicke, J. Shen, Y. Okamoto, P. G. Jones, H. Hopf. *Angew. Chem. Int. Ed.* **2012**, *51*, 12884 – 12887.

2.5 Triquinacene derivatives

- Ortho-substituted tribenzotriquinacenes
- C_1-chiral derivative

Compound	HTP	Specific rotation α
67	-	297
68	5	435



G. Markopoulos, L. Henneicke, J. Shen, Y. Okamoto, P. G. Jones, H. Hopf. Angew. Chem. Int. Ed. 2012, 51, 12884 – 12887.

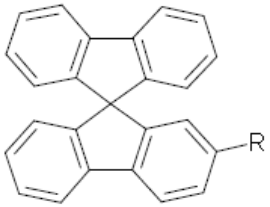
3. Summary & outlook

3.1 Summary

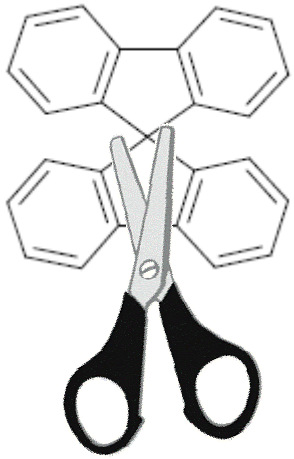
- Synthesized dopants have promising HTP
- Bridged Binaphthyls generate the highest HTP (dependent on the substituent)
- Helical molecules like [5]helicenes can be stable as single enantiomers
- Triptycenes are probably no good inducers
- Naphthyl-tribenzotriquinacene – interesting new structure

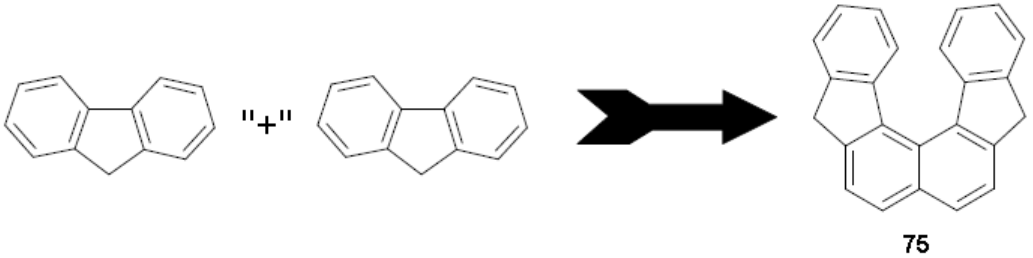
3.1 Outlook

- Spiro compounds
- Spirobifluorene



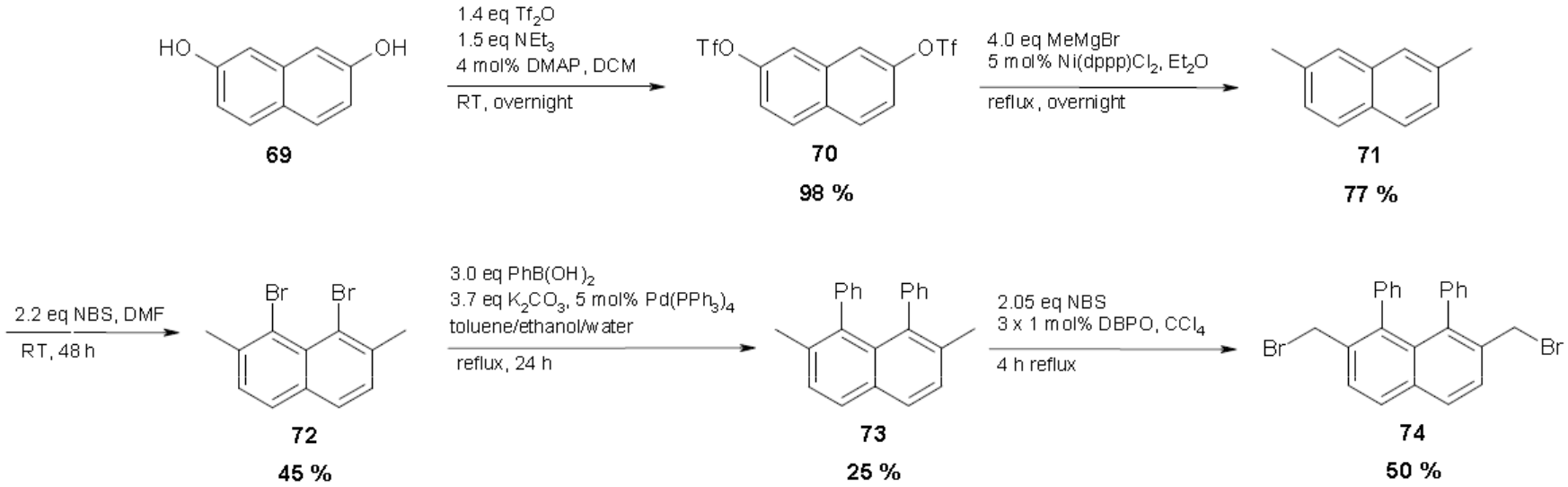
- Current project: fluorene-like helicene



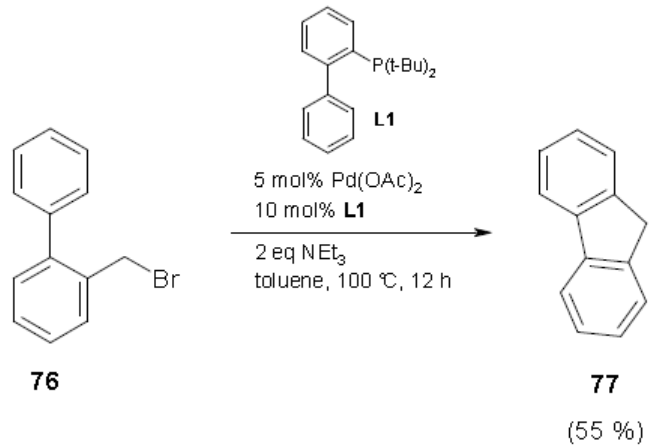


- 6 step approach to generate **75**

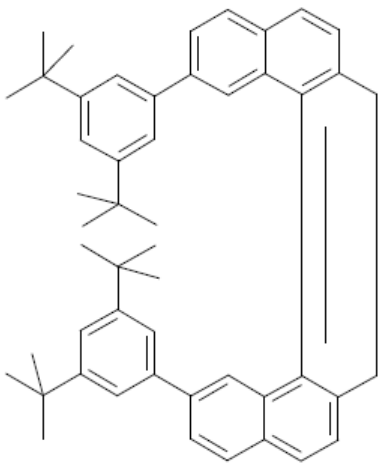
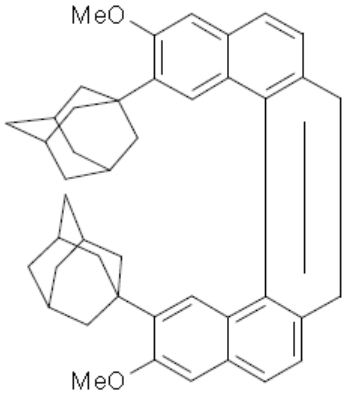
3.2 Outlook

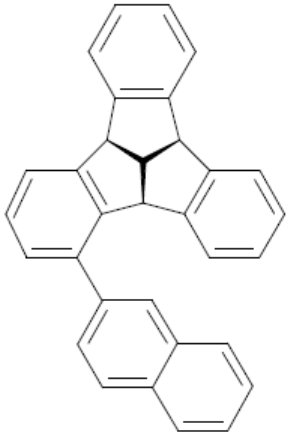
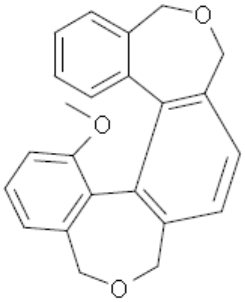


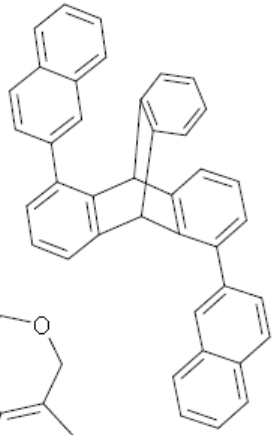
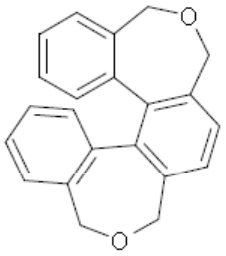
Pd-catalyzed Cyclization of
2-Phenylbenzyl halides:

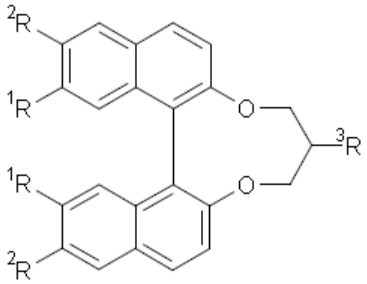


S. J. Hwang, H. J. Kim, S. Chang. *Org. Lett.* **2009**, *11*, 4588 – 4591. S. J. Hwang, S. H. Cho, S. Chang. *J. Am. Chem. Soc.* **2008**, *130*, 16158 – 16159.



Thank you!