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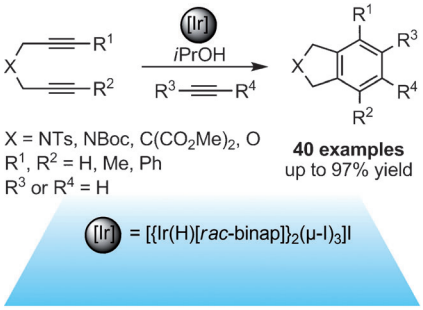
Triple-edged sword: Isoindoline, indane, and dihydroisobenzofuran derivatives are synthesized by using a triply halogen-bridged iridium(III) complex in the [2+2+2] cycloaddition of α,ω-diynes with alkynes. A broad range of substitution groups such as alcohol, alkyl, ether, and halogen can be used and the chemistry extended to prepare the corresponding borylated fused arenes.



A.-L. Auvinet, M. Ez-Zoubir, S. Bompard, M. R. Vitale, J. A. Brown, V. Michelet, V. Ratovelomanana-Vidal**

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Iridium(III)-Catalyzed Approach for the Synthesis of Fused Arenes: Access to Isoindolines, Indanes, and Dihydroisobenzofurans

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Iridium(III)-Catalyzed Approach for the Synthesis of Fused Arenes: Access to Isoindolines, Indanes, and Dihydroisobenzofurans

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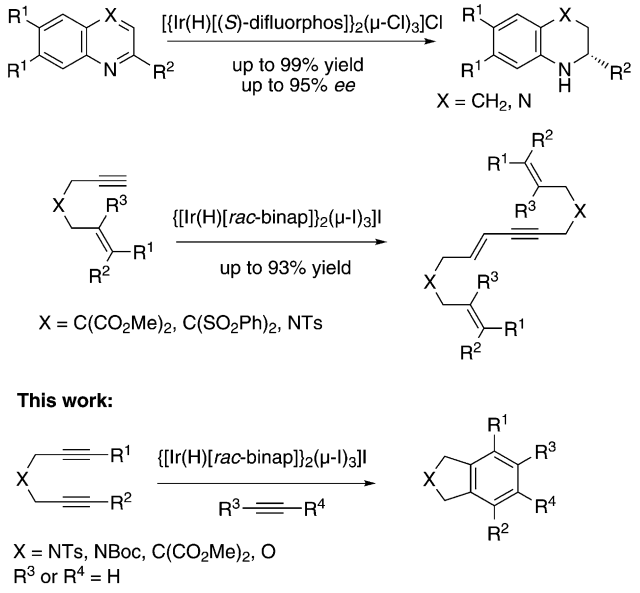
Dedicated to Professor Irina P. Beletskaya for her tremendous contribution to metal-catalyzed reactions

A facile and efficient method for the synthesis of isoindoline, indane, and dihydroisobenzofuran derivatives has been developed through the application of a halogen-bridged iridium(III) complex to the [2+2+2] cycloaddition of α,ω-diynes with alkynes. The cycloaddition tolerates a broad range of substitution groups, such as alcohol, alkyl, ether, and halogen, and the chemistry can be extended to prepare the corresponding borylated fused arenes. The reaction shows that hindered starting materials are also good partners, which provide the desired fused arenes in good yields.

Introduction

Fused arenes are key motifs present in a number of biologically active compounds, and the development of diverse synthetic methods for their preparation and subsequent functionalization is of considerable interest.[1] In this context, benzannulation holds promise for converting simple and generally available raw materials into elaborate complex molecules, such as pharmaceutical and natural products. In addition, ring synthesis is the most straightforward and atom-economical route to prepare polysubstituted benzene derivatives and, compared to existing Friedel–Crafts functionalization methodologies, has the advantage of not being limited to specific substitution groups governed by the preexisting directing groups.[2] Transition-metal complexes are indispensable tools for organic synthesis and have proven their synthetic utility in the preparation of complex and heavily substituted benzene-derived systems.[3] Iridium(III) complexes have been explored less,[4] although they have a great potential in C–H and C–C bond-forming processes (Scheme 1). In our previous reports, we demonstrated the versatility of halogen-bridged iridium(III) complexes.[5] Notably, such catalytically active species proved to be highly efficient in the asymmetric hydrogenation of a wide range of unsaturated C=N bonds present in cyclic imines, quinolines, quinolinium salts, and quinoxalines.[6] In addition, the catalyst system was excellent for mediating the stereoselective dimerization of enynes.[7] We showed recently that the iodo-bridged iridium(III) catalyst system [{Ir(H)[*rac*-binap]}$_2$(μ-I)$_3$]I could be involved in the [2+2+2] cycloaddition of α,ω-diynes and alkynes to provide the biologically relevant isoindoline scaffolds.[8] We developed a reliable and robust iridium(III)-catalyzed strategy that enables the synthesis of various fused isoindolines with



Scheme 1. C–H and C–C bond-forming processes.

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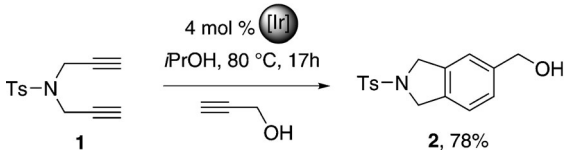
a common and environmentally friendly solvent such as 2-propanol. To extend our endeavors to the synthesis and study of aromatic compounds, we used this catalyst system for the preparation of the corresponding carbon- and oxygen-based fused arenes.

Herein, we report the detailed results of our studies of the [2+2+2] cycloaddition of α,ω-diynes and alkynes in the presence of our catalyst system, which yields isoindoline, indane, and dihydroisobenzofuran derivatives.

Results and Discussion

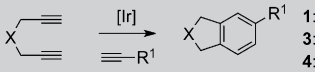
In our preliminary studies, diyne **1** was reacted with 3 equiv. of propargyl alcohol to give an isoindoline derivative **2** in the presence of a catalytic amount of [{Ir(H)[*rac*-binap]}$_2$(μ-I)$_3$]I.[8] The catalytic activity varied according to the solvent. Reaction optimization showed that 2-propanol was the most efficient solvent to perform the reaction. The reaction was completed within 17 h at 80 °C, which furnished the desired isoindoline **2** in satisfactory 78% yield (Scheme 2).



Scheme 2. [{Ir(H)[*rac*-binap]}$_2$(μ-I)$_3$]I-catalyzed reaction of diyne **1** with 3 equiv. of propargyl alcohol toward isoindoline derivative **2**.[8]

We reported previously that diynes **1** and **3** reacted with terminal alkynes to give the corresponding isoindoline derivatives in good to excellent yields.[8] With these promising results in hand, we decided to apply the methodology to diynes **4** and **5**. The results are summarized in Table 1. Then, propargyl alcohol underwent cycloaddition with malonate-based diyne **4**, oxygen-based diyne **5**, and nitrogen-based diyne **3**, which afforded the desired fused arenes: indane **6** (entry 1), dihydrobenzofuran **7** (entry 2), and isoindoline **8** (entry 3) in 76, 68, and 85% yields, respectively. Another alkynyl alcohol, 3-butyn-1-ol, was evaluated with different diynes; **1**, **3**, and **4**. The cycloaddition was successful in the formation of compound **9** (entry 4), compound **10** (entry 5), and alcohol **11** (entry 6) in excellent yield (up to 90%). Various substitution groups were shown to be tolerated on the alkyne partner. Methyl propargyl ether provided the corresponding fused arenes **12** (entry 7), **13** (entry 8), and **14** (entry 9) in good yields (64–77%). We then studied the cycloaddition with alkyl-substituted alkynes such as *n*-hexyne, cyclopropylacetylene, and 1-chloro-pent-4-yne (entries 10–18). Thus, we could access compounds **15–17** with satisfactory yields (entries 10–12). The cyclopropyl-substituted **18** was obtained in 82% yield by using 8 mol% of the iridium complex (entry 13). Cycloadducts **19–21** were observed in acceptable yields (entries 14–16). Finally, the reaction of diynes **4** and **1** with the halogen-substituted alkyne led to the desired compounds **22** and **23** in 40 and 61% yields, respectively (entries 17 and 18). The cycloaddition with aryl-substituted al-

Table 1. Substrate scope with terminal diynes and terminal alkynes.[a]



1: X = NTs
3: X = NBoc
4: X = C(CO$_2$Me)$_2$
5: X = O

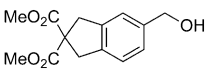
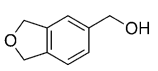
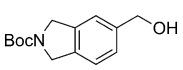
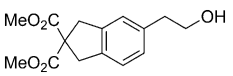
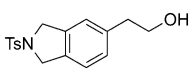
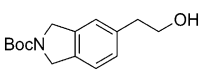
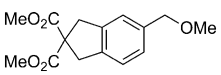
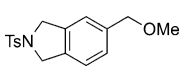
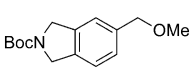
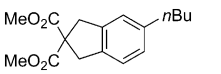
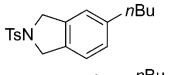
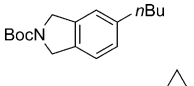
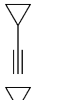
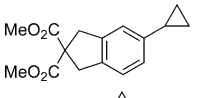
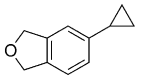
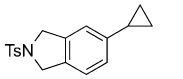
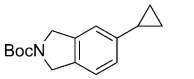
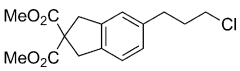
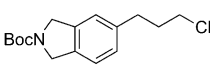
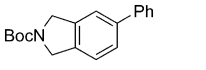
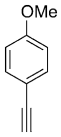
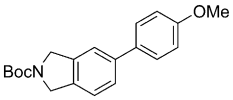
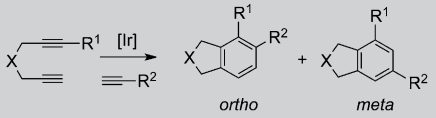
Entry	X	Alkyne	Product		Yield [%]
1	C(CO$_2$Me)$_2$			**6**	76
2	O			**7**	68
3	NBoc			**8**	85
4	C(CO$_2$Me)$_2$			**9**	70
5	NTs			**10**	69
6	NBoc			**11**	90
7	C(CO$_2$Me)$_2$			**12**	77
8	NTs			**13**	70
9	NBoc			**14**	64
10	C(CO$_2$Me)$_2$			**15**	87[c]
11	NTs			**16**	62[c]
12	NBoc			**17**	63[c]
13	C(CO$_2$Me)$_2$			**18**	82[c,d]
14	O			**19**	30[c]
15	NTs			**20**	61[c]
16	NBoc			**21**	66[c]
17	C(CO$_2$Me)$_2$			**22**	40[c]
18	NBoc			**23**	61[c]
19	NBoc			**24**	47
20	NBoc			**25**	59

Table 1. (Continued)

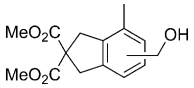
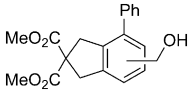
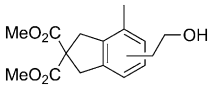
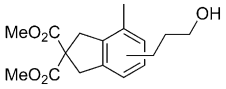
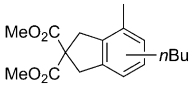
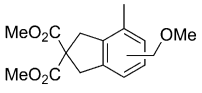
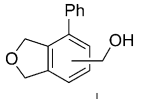
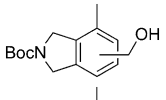
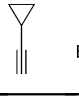
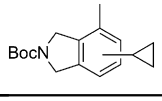
Entry	X	Alkyne	Product		Yield [%]
21	NBoc			**26**	52

[a] Reaction conditions: 1 equiv. of the diyne, 3 equiv. of the alkyne, 4 mol% of $[\{Ir(H)[rac\text{-binap}]\}_2(\mu\text{-}I)_3]I$ in 1 mL of 2-propanol stirred at 80 or 110 °C for 17 h; [b] Isolated yield; [c] 10 equiv. of the alkyne; [d] 8 mol% of $[\{Ir(H)[rac\text{-binap}]\}_2(\mu\text{-}I)_3]I$.

Table 2. Cycloaddition with unsymmetrical diynes and terminal alkynes.[a]



27: X = $C(CO_2Me)_2$, R^1 = Me
28: X = $C(CO_2Me)_2$, R^1 = Ph
29: X = O, R^1 = Ph
30: X = NBoc, R^1 = Me

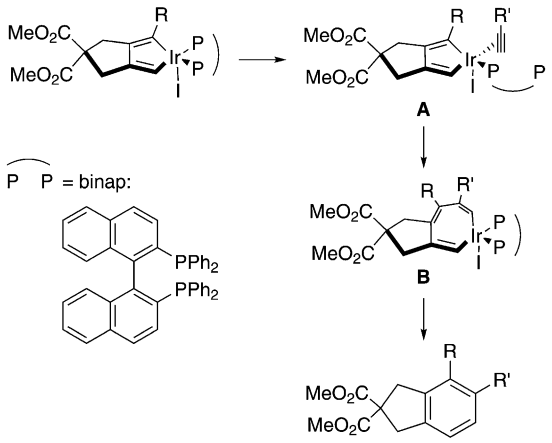
Entry	Diyne	Alkyne	Product	Diyne	Yield[b] [%] (*ortho*/*meta* ratio)[c]
1	**27**			**31**	60 (58:42)
2	**28**			**32**	62 (50:50)
3	**27**			**33**	70 (71:29)
4	**27**			**34**	33 (78:22)
5	**27**			**35**	78 (72:28)
6	**27**			**36**	64 (63:37)
7	**29**			**37**	61 (71:29)
8	**30**			**38**	97 (72:28)
9[d]	**30**			**39**	27 (67:33)

[a] Reaction conditions: 1 equiv. of the diyne, 3 equiv. of the alkyne, 4 mol% of $[\{Ir(H)[rac\text{-binap}]\}_2(\mu\text{-}I)_3]I$ in 1 mL of 2-propanol stirred at 80 or 110 °C for 17 h; [b] Isolated yield; [c] Determined from ^1H NMR analysis of the crude reaction mixture; [d] 10 equiv. of the alkyne.

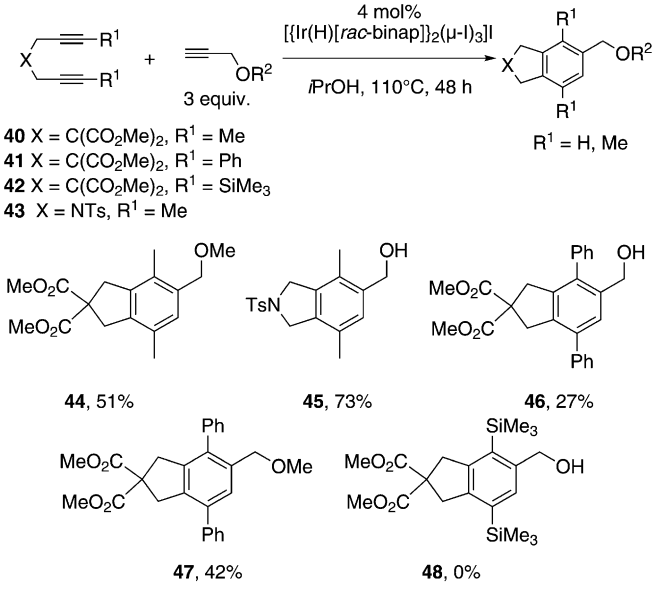
kynes was also successful, which led to the corresponding isoindolines **24–26** in good yields (entries 19–21).

We next turned our attention to monosubstituted diynes. The reaction provided the desired compounds, in most cases favoring the *ortho* regioisomer. The results are summarized in Table 2. We first looked at diyne malonates bearing sp^3 (methyl **27**) and sp^2 (phenyl **28)** centers. The reaction performed in the presence of propargyl alcohol and diyne malonates **27** and **28** showed a slight improvement in the regioselectivity in the case of the methyl-substituted diyne **27**. The methyl group has a significant effect on the regioselectivity of the cyclization, probably because of the presence of an sp^3 center, which is more sterically demanding than that of the more planar sp^2 center; this explains the *ortho*/*meta* ratio of 50:50 obtained with aryl substituents. As the steric hindrance seemed to play a role in the regioselectivity, we investigated the same reaction with a different side-chain length within the alkyne partner. We can clearly see that the regioselectivity that is in favor of the *ortho* isomer increased with the length of the side chain. A ratio of 58:42 was observed with propargyl alcohol (entry 1), and a significant improvement was observed with 3-butyn-1-ol (entry 3) and 4-pentyn-1-ol, which provided **34** with a ratio of 78:22 in favor of the *ortho* isomer (entry 4). The use of *n*-hexyne gave a regiospecificity (entry 5) similar to that obtained with 3-butyn-1-ol (entry 3). We also performed the reaction with methyl propargyl ether; however, no significant improvement was observed (entry 6). To expand the scope of the reaction, oxygen- and nitrogen-tethered diynes were tested. The cycloaddition of monosubstituted dipropargyl ether **29** was studied in the presence of propargyl alcohol. The desired compound **37** was obtained with satisfactory regioselectivity (entry 7). The cycloaddition of *N*-Boc-protected diyne **30** with propargyl alcohol furnished the desired compound in excellent yield and with good regioselectivity (entry 8). The reaction was also successful with cyclopropylacetylene, which delivers the desired product with useful regioselectivity (entry 9). By comparing carbon-, oxygen-, and nitrogen-based diynes, one may observe that a better regiocontrol is observed in the case of the heteroatom-linked derivatives. Propargyl alcohol as the alkyne partner seems to approach differently, depending on the nature of the diyne tether (entries 1, 2, 7, and 8). This may be due to a higher steric hindrance of the malonate moiety, which could disturb the insertion of the alkyne partner and thus give lower regioselectivities.

The results from the experiments detailed above demonstrate that the *ortho* regioisomer is favored, which can be rationalized in Scheme 3. As binap has a bite angle comparable to that of DPPF,[9] we can assume that the initial oxidative cyclization of the iridium complex with the diyne is followed by the dissociation of one phosphorus moiety of binap because of the steric hindrance of the substituent (methyl, phenyl) from the diyne (Scheme 4); this hypothesis is in agreement with Takeuchi's work.[4a] Then, the alkyne could fill the vacancy through coordination to iridium, which leads to intermediate **A**. The insertion step toward iridium–cycloheptadiene **B** would be followed by a reductive elimination, which would preferentially afford the *ortho* isomer of the benzanulated product.



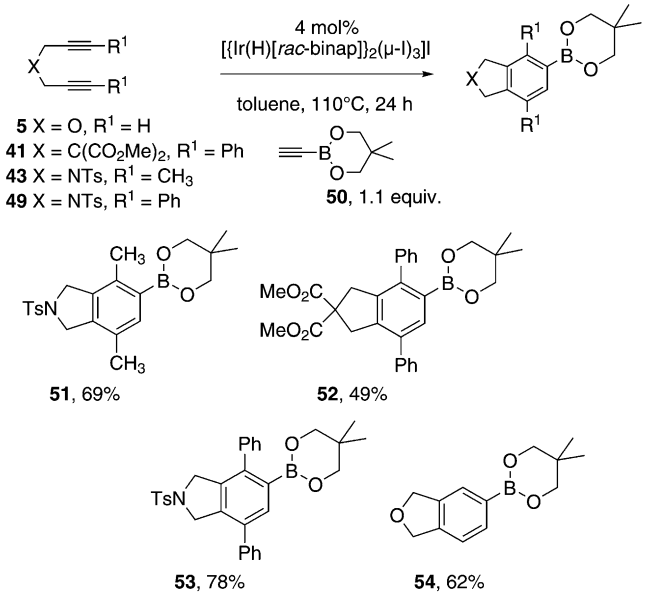
Scheme 3. Reaction mechanism accountable for the formation of the *ortho* isomer of the benzanulated product.



Scheme 4. Cycloaddition with disubstituted diynes and terminal alkynes.

To evaluate the limit of the catalyst system, we studied the challenging and less well explored reactivity of alkyl- and aryl-disubstituted diynes. The results presented in Scheme 4 indicate that a range of different functional groups can be tolerated. The steric hindrance of the substituent on the diyne has a significant effect on the reaction outcome. The reaction performed with alkyl-substituted diyne malonate **40** was successful and provided **44** in 51% yield. The NTs (Ts = tosyl) diyne **43** also proved to be a good partner, as the corresponding cycloadduct **45** was isolated in 73% yield. The aryl-substituted diyne **41** reacted sluggishly with propargyl alcohol to give **46** in 27% yield, whereas a slight improvement could be observed with methyl propargyl ether, which led to **47** in 42% yield. As expected, the reaction of the highly hindered silylated-substituted diyne **42** proved to be unsuccessful, probably because of the prominent steric hindrance generated by trimethylsilyl substituents.

Owing to the synthetic utility of aromatic boronic esters, we also envisaged the use of alkynylboronates in this study.[10] The reaction was performed in toluene to prevent transesterification of the boronate moiety (Scheme 5). The terminal alkynylboronate **50** proved to be an excellent partner as the reaction



Scheme 5. Cycloaddition with alkynylboronates toward aromatic boronic esters.

proceeded smoothly to afford the desired structures in good yields. The cycloaddition performed well with alkyl- and aryl-substituted diynes such as nitrogen-, malonate-, and oxygen-tethered diynes, which furnished the highly substituted boryl isoindolines **51** and **53** in good yields as well as boryl indane **52** and boryl dihydroxyisobenzofuran **54**, which were isolated in 49 and 62% yields, respectively. Notably, disubstituted diynes reacted similarly as observed previously in Scheme 4, which makes our catalyst system highly versatile with regard to the choice of the alkyne partner.

Conclusions

In summary, we have developed a convenient and efficient protocol for the preparation of fused arenes. Isoindolines, indanes, and dihydroisobenzofurans bearing a wide range of substitution groups could be accessed through an iridium(III)-catalyzed [2+2+2] cycloaddition of α,ω-diynes with alkynes. The reaction proceeds with symmetrical and unsymmetrical diynes, which affords highly substituted benzene derivatives in good to excellent yields (up to 97%). This methodology can be applied to alkynylboronates, which is a convenient means to generate the challenging, highly functionalized borylated fused arenes that present great potential for further elaboration. Notably, these processes are extremely robust and simple to perform. The catalyst system is compatible with commercial grade non-degassed solvents, whereas the alkynes herein do

not necessitate purification before use. For these reasons, this iridium(III)-catalyzed [2+2+2] cycloaddition is a practical and attractive synthetic method.

Experimental Section

General

^{1}H NMR and ^{13}C NMR signals were internally referenced to residual protio solvent signals. Coupling constants (*J*) referred to apparent peak multiplicities. High-resolution mass spectra were performed at the Université Pierre et Marie Curie (Paris). Toluene was distilled over calcium hydride, and 2-propanol (Normapur grade) was used without further purification. [{Ir(H)[*rac*-binap]}$_2$(μ-I)$_3$]I was prepared according to the method described in the literature.[5]

Materials

Diynes **1**, **3**, **4**, **27–30**, **40–43**, **49** and alkynylboronate **50** were prepared according to methods described in the literature (see the Supporting Information). Diyne **5** was purchased from Aldrich and used without further purification.

Cycloaddition of diynes with alkynes

General procedure: [{Ir(H)[*rac*-binap]}$_2$(μ-I)$_3$]I (4 mol%) and 2-propanol (2 mL/0.4 mmol of the diyne) were added to a sealed tube. The mixture was stirred under argon for 5 min at RT. Then, the diyne (1 equiv.) was added, followed by the addition of the alkyne (3 or 10 equiv.). The tube was sealed, and the reaction mixture was stirred at 80–110 °C for 17–48 h. Purification of the crude mixture by using flash chromatography over silica gel provided the desired compound.

The analytical data obtained for cycloaddition products **2**,[11a] **6**,[4a] **7**,[11b] **8**,[11c] **9**,[4a] **10**,[8] **11**,[8] **12**,[4a] **13**,[8] **14**,[8] **15**,[4a] **16**,[11d] **17**,[11e] **20**,[8] **21**,[8] **22**,[4a] **23**,[8] **24**,[11e] **25**,[8] **26**,[8] **34**,[4a] **35**,[4a] **38**,[8] **39**,[8] **44**,[4a] **45**,[8] **51**,[8] **53**,[8] and **54**[11f] were in agreement with those reported in the literature.

Dimethyl 5-cyclopropyl-1*H*-indene-2,2(3*H*)-dicarboxylate (18): Starting from diyne **4** (38.7 mg, 0.18 mmol), compound **18** was isolated as a yellow oil (42.0 mg, 82% yield). ^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.54–0.60 (m, 2H), 0.81–0.87 (m, 2H), 1.78 (tt, J = 8.5, 5.1 Hz, 1H), 3.47 (s, 4H), 3.66 (s, 6H), 6.80–6.83 (m, 2H), 6.99 ppm (d, J = 8.0 Hz, 1H); ^{13}C NMR (75 MHz, $CDCl_3$): δ = 8.0, 14.2, 39.2, 39.5, 51.9, 59.5, 120.4, 122.9, 123.7, 135.9, 139.0, 141.9, 171.1 ppm; HRMS (EI): *m/z*: calcd for $C_{16}H_{19}O_4$: 275.1278 $[M+H]^+$; found: 275.1278.

5-Cyclopropyl-1,3-dihydroisobenzofuran (19): Starting from diyne **5** (37.6 mg, 0.40 mmol), the reaction afforded compound **19** as a yellow oil (19.0 mg, 30% yield). ^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.58–0.63 (m, 2H), 0.85–0.92 (m, 2H), 1.80–1.89 (m, 1H), 4.99 (s, 4H), 6.87–6.93 (m, 2H), 7.04 ppm (d, J = 8.0 Hz, 1H); ^{13}C NMR (75 MHz, $CDCl_3$): δ = 8.8, 14.9, 72.9, 73.0, 117.6, 120.2, 124.6, 135.8, 138.9, 142.9 ppm; HRMS (EI): *m/z*: calcd for $C_{11}H_{11}O$: 159.0804 $[M-H]^+$; found: 159.0806.

Dimethyl 5-(hydroxymethyl)-4-methyl-1*H*-indene-2,2(3*H*)-dicarboxylate and dimethyl 6-(hydroxymethyl)-4-methyl-1*H*-indene-2,2(3*H*)-dicarboxylate (31*o*/31*m*): Starting from diyne **27** (41.3 mg, 0.19 mmol), the reaction afforded compound **31** as a yellow oil and as an inseparable 58:42 mixture of *ortho*/*meta* regioisomers **31*o*/31*m*** (31 mg, 60% yield). ^{1}H NMR (300 MHz, $CDCl_3$): δ = 2.26 (s, 1.26H*m*), 2.26 (s, 1.74H*o*), 3.51–3.60 (m, 4H*o*,*m*), 3.75 (s, 6H*o*,*m*), 4.61 (d, J = 5.5 Hz, 0.84H*m*), 4.67 (d, J = 5.4 Hz, 1.16H*o*), 7.07–6.96 (m, 1.42H*o*,*m*), 7.17 ppm (d, J = 7.7 Hz, 0.58H*o*); ^{13}C NMR (75 MHz, $CDCl_3$): δ = 15.0, 18.9, 39.2, 39.6, 40.6 (2C), 53.0 (2C), 59.9 (2C), 63.4, 65.2, 120.3, 121.4, 126.9, 127.4, 132.2, 133.8, 137.3, 138.2, 139.3, 139.6, 140.0, 140.2, 172.2 ppm (2C); HRMS (ESI) *m/z*: calcd for $C_{15}H_{18}O_5Na$: 301.1046 $[M+Na]^+$; found: 301.1048.

Dimethyl 5-(hydroxymethyl)-4-phenyl-1*H*-indene-2,2(3*H*)-dicarboxylate and dimethyl 6-(hydroxymethyl)-4-phenyl-1*H*-indene-2,2(3*H*)-dicarboxylate (32*o*/32*m*): Starting from diyne **28** (56.9 mg, 0.20 mmol), the reaction afforded compounds **32o** and **32m** separately as yellow oils [21 mg (**32*o***) and 21.0 mg (**32*m***), 50:50 mixture of *ortho*/*meta* regioisomers **32*o*/32*m***, 62% global yield]. **32*o***: ^{1}H NMR (300 MHz, $CDCl_3$): δ = 3.34 (s, 2H), 3.67 (s, 2H), 3.72 (s, 6H), 4.46 (s, 2H), 7.22–7.31 (m, 2H), 7.37–7.48 ppm (m, 5H); ^{13}C NMR (75 MHz, $CDCl_3$): δ = 40.1, 40.7, 52.9, 60.2, 63.0, 123.5, 127.4, 127.5, 128.6, 128.9, 137.2, 137.6, 138.4, 139.2, 139.4, 172.0 ppm; **32*m***: ^{1}H NMR (300 MHz, $CDCl_3$) δ = 3.66 (s, 4H), 3.74 (s, 6H), 4.71 (s, 2H), 7.23–7.24 (m, 2H), 7.34–7.41 (m, 2H), 7.45–7.46 ppm (m, 3H); ^{13}C NMR (75 MHz, $CDCl_3$): δ = 40.1, 40.6, 53.0, 60.4, 65.3, 121.9, 126.5, 127.2, 128.4, 128.9, 137.1, 138.5, 140.4, 140.5, 141.1, 172.0 ppm; HRMS (ESI): *m/z*: calcd for $C_{20}H_{20}O_5Na$: 363.1203 $[M+Na]^+$; found: 363.1205.

Dimethyl 5-(2-hydroxyethyl)-4-methyl-1*H*-indene-2,2(3*H*)-dicarboxylate and dimethyl 6-(2-hydroxyethyl)-4-methyl-1*H*-indene-2,2(3*H*)-dicarboxylate (33*o*/33*m*): Starting from diyne **27** (41.3 mg, 0.19 mmol), the reaction afforded compound **33** as a yellow oil and as an inseparable 71:29 mixture of *ortho*/*meta* regioisomers **33*o*/33*m*** (38.0 mg, 70% yield). ^{1}H NMR (300 MHz, $CDCl_3$): δ = 2.22 (s, 2.13H*o*), 2.23 (s, 0.87H*m*), 2.79 (t, J = 6.5 Hz, 0.58H*m*), 2.87 (t, J = 6.8 Hz, 1.42H*o*), 3.46–3.62 (m, 5H*o*,*m*), 3.70–3.86 (m, 2H*o*,*m*), 3.75 (s, 6H*o*,*m*), 6.84 (s, 0.29H*m*), 6.89 (s, 0.29H*m*), 6.97 (d, J = 7.8 Hz, 0.71H*o*), 7.01 ppm (d, J = 7.8 Hz, 0.71H*o*); ^{13}C NMR (75 MHz, $CDCl_3$): δ = 15.6, 19.0, 36.2, 38.9, 39.2, 40.0, 40.7, 45.8, 53.0 (2C), 59.8 (2C), 62.8, 63.7, 121.4, 122.1, 128.7, 129.0, 132.3, 133.8, 134.9, 137.0, 137.6, 137.9, 139.6, 140.0, 172.3 ppm (2C); HRMS (EI): *m/z*: calcd for $C_{16}H_{20}O_5Na$: 315.1203 $[M+Na]^+$; found: 315.1201.

Dimethyl 5-(methoxymethyl)-4-methyl-1*H*-indene-2,2(3*H*)-dicarboxylate and dimethyl 6-(methoxymethyl)-4-methyl-1*H*-indene-2,2(3*H*)-dicarboxylate (36*o*/36*m*): Starting from diyne **27** (41.3 mg, 0.19 mmol), the reaction afforded compound **36** as a yellow oil and as an inseparable 61:39 mixture of *ortho*/*meta* regioisomers **36*o*/36*m*** (34.8 mg, 64% yield). ^{1}H NMR (300 MHz, $CDCl_3$): δ = 2.24 (s, 1.83H*o*), 2.25 (s, 1.17H*m*), 3.37 (s, 1.17H*m*), 3.38 (s, 1.83H*o*), 3.51–3.60 (m, 4H*o*,*m*), 3.75 (s, 6H*o*,*m*), 4.37 (s, 0.78H*m*), 4.41 (s, 1.22H*o*), 6.93–7.05 (m, 1.39H*o*,*m*), 7.13 ppm (d, 0.61H*o*); ^{13}C NMR (75 MHz, $CDCl_3$): δ = 15.0, 18.9, 39.2, 39.7, 40.7 (2C), 52.9 (2C), 58.1 (2C), 59.9 (2C), 73.1, 74.7, 121.0, 121.1, 127.6, 128.3, 132.7, 133.7, 134.6, 137.3, 138.3, 139.4, 139.5, 139.9, 172.2 ppm (2C); HRMS (EI): *m/z*: calcd for $C_{16}H_{20}O_5Na$: 315.1203 $[M+Na]^+$; found: 315.1204.

(4-Phenyl-1,3-dihydroisobenzofuran-5-yl)methanol and (7-phenyl-1,3-dihydroisobenzo-furan-5-yl)methanol (37*o*/37*m*): Starting from diyne **29** (100.0 mg, 0.59 mmol), the reaction afforded compounds **37 o** and **37 m** separately as yellow oils [41.7 mg (**37*o***) and 17.1 mg (**37*m***), 71:29 mixture of *ortho*/*meta* regioisomers **37*o*/37*m***, 61% global yield]. **37*o***: ^{1}H NMR (300 MHz, $CDCl_3$): δ = 4.42 (s, 2H), 4.78 (s, 2H), 5.09 (s, 2H), 7.15–7.18 (m, 2H), 7.30–7.41 ppm (m, 5H); ^{13}C NMR (75 MHz, $CDCl_3$): δ = 62.6, 73.3, 74.0, 120.2, 127.7, 127.9, 128.5, 128.6, 135.1, 137.6, 138.0, 138.6, 138.7 ppm; **37*m***: ^{1}H NMR (300 MHz, $CDCl_3$): δ = 4.69 (s, 2H), 5.09–5.11 (m, 4H), 7.18 (s, 1H), 7.25 (s, 1H), 7.27–7.39 ppm (m, 5H); ^{13}C NMR (75 MHz, $CDCl_3$): δ =

65.2, 73.4, 73.7, 118.6, 126.4, 127.7, 127.9, 128.8, 136.3, 136.7, 140.0, 140.7, 141.2 ppm; HRMS (ESI): *m/z*: calcd for $C_{15}H_{13}O_2$: 225.0910 $[M-H]^+$; found: 225.0910.

Dimethyl 5-(hydroxymethyl)-4,7-diphenyl-1*H*-indene-2,2(3*H*)-dicarboxylate (46): Starting from diyne **41** (69.3 mg, 0.19 mmol), the reaction afforded compound **46** as a yellow oil (21.6 mg, 27% yield). ^{1}H NMR (300 MHz, $CDCl_3$): $\delta = 3.30$ (s, 2H), 3.61 (s, 6H), 3.65 (s, 2H), 4.43 (s, 2H), 7.22–7.25 (m, 2H), 7.29–7.45 ppm (m, 9H); ^{13}C NMR (75 MHz, $CDCl_3$): $\delta = 40.2$, 40.5, 52.9, 60.2, 63.1, 127.3, 127.5, 128.0 (2C), 128.5, 128.6, 128.9, 136.6, 136.9, 137.6, 137.9, 138.3, 140.0, 140.3, 171.9 ppm; HRMS (EI): *m/z*: calcd for $C_{26}H_{24}O_5Na$: 439.1516 $[M+Na]^+$; found: 439.1516.

Dimethyl 5-(methoxymethyl)-4,7-diphenyl-1*H*-indene-2,2(3*H*)-dicarboxylate (47): Starting from diyne **41** (69.3 mg, 0.19 mmol), the reaction afforded compound **47** as a yellow oil (34.8 mg, 42% yield). ^{1}H NMR (300 MHz, $CDCl_3$): $\delta = 3.27$ (s, 3H), 3.39 (s, 2H), 3.68 (s, 6H), 3.71 (s, 2H), 4.22 (s, 2H), 7.29–7.33 (m, 2H), 7.36–7.52 ppm (m, 9H); ^{13}C NMR (75 MHz, $CDCl_3$): $\delta = 40.3$, 40.5, 52.9, 58.2, 60.2, 72.2, 127.1, 127.2, 128.3, 128.4 (2C), 128.5, 129.1, 135.3, 136.9, 137.0, 137.4, 138.5, 139.7, 140.4, 171.9 ppm; HRMS (EI): *m/z*: calcd for $C_{27}H_{26}O_5Na$: 453.1672 $[M+Na]^+$; found: 453.1670.

Dimethyl 5-(5,5-dimethyl-1,3,2-dioxaborinan-2-yl)-4,7-diphenyl-1*H*-indene-2,2(3*H*)-dicarboxylate (52): Starting from diyne **41** (100.0 mg, 0.028 mmol), the reaction afforded compound **52** as a yellow oil (67.7 mg, 49% yield). ^{1}H NMR (300 MHz, $CDCl_3$): $\delta =$ 0.87 (s, 6H), 3.48 (s, 6H), 3.67–3.70 (m, 8H), 7.29–7.52 (m, 10H), 7.59 ppm (s, 1H); ^{13}C NMR (75 MHz, $CDCl_3$): $\delta = 21.9$, 31.6, 40.5, 40.8, 53.0, 60.2, 73.3, 126.6, 127.0, 127.7, 128.4, 128.7, 129.0, 133.7, 136.7, 138.8, 139.1, 140.8, 142.1, 142.3, 172.1 ppm; HRMS (ESI): *m/z*: calcd for $C_{30}H_{31}O_6BNa$: 521.2106 $[M+Na]^+$; found: 521.2108.

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Keywords: alkynes · cycloaddition · diynes · fused-ring systems · iridium

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