RESEARCH ARTICLE doi.org/10.1002/adsc.202200526

Advanced Synthesis & Catalysis

Diastereoselective and Synergistic Gold-Catalyzed Bispropargylation of Xanthones and Thioxanthones: An Access to Xanthene Derivatives

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Manuscript received: May 16, 2022; Revised manuscript received: June 22, 2022;
Version of record online: July 12, 2022

Supporting information for this article is available on the WWW under https://doi.org/10.1002/adsc.202200526

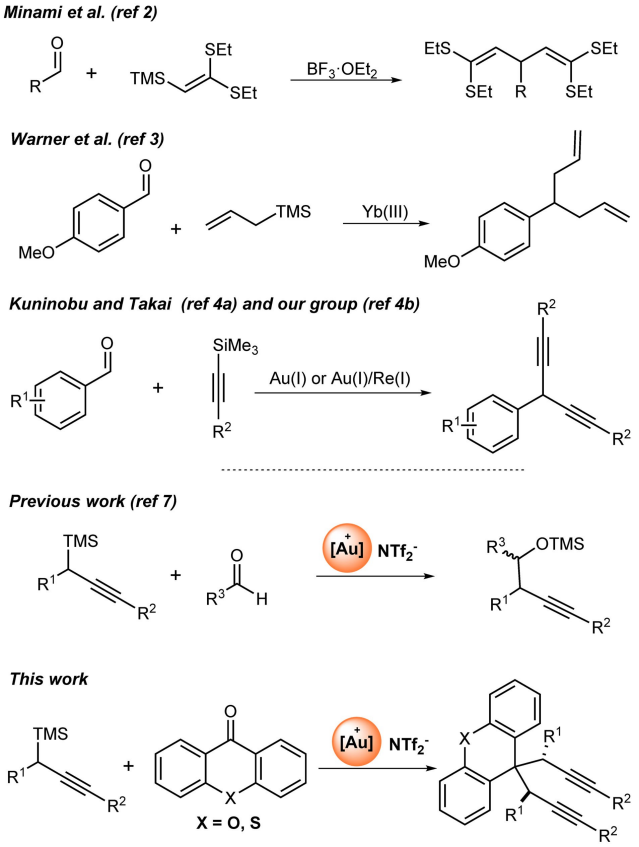
Abstract: A gold-catalyzed bispropargylation of xanthone derivatives is described. The use of propargylsilanes permits to achieve a deoxygenative bispropargylation through a double catalytic addition of the corresponding allenylgold intermediate to the synergistically activated carbonyl moiety. This methodology works in a diastereoselective manner either with xanthone or thioxanthone derivatives. Monopropargylated xanthydrol silyl ethers were isolated as reaction intermediates and these species could be transformed into symmetrical and non-symmetrical bispropargylated xanthenes. The formation of non-symmetrical bispropargylated xanthenes could also be achieved through an one-pot procedure. Finally, other interesting structures, such as propargylxanthylidenes, propargylxanthenes and bispropargylated xanthenes replacing the silicon moiety, were accessible following different one-pot synthetic methodologies. In addition, bispropargylated xanthenes could perform a carbonylative [2 + 2 + 1] formal cycloaddition.

Keywords: Gold; Homogeneous catalysis; Silanes; Synthetic methods; Xanthenes.

Introduction

Addition of organometallic reagents to carbonyls has been a powerful and widely studied tool in organic synthesis over decades. Classical procedures used to be stoichiometric and not always easy to control, so the development of useful catalytic methodologies to achieve these transformations became sometimes a challenging quest.[1] Although catalyzed addition reactions are well studied, selective deoxygenative introduction of two equivalents of these nucleophiles has received scarce attention. In this sense, only two processes involving catalytic bisvinylation[2] or bisallylation[3] and two examples of bisalkynylation[4] reactions have been described (Scheme 1, top). However, catalytic bispropargylation processes remain unexplored.[5]

On the other hand, the development and study of new gold-catalyzed organic transformations for introducing molecular complexity is still a hot topic nowadays.[6] In this sense, our research group described a bisalkynylation process using alkynylsilanes,[4b] and more recently we have developed a gold-catalyzed propargylation methodology[7] of carbonyl derivatives employing propargylsilanes (Scheme 1, middle). For this propargylation reaction, an elusive σ-gold allenyl complex was confirmed as the key intermediate and could be isolated and characterized.[7a] In both cases, the carbonyl compound is synergistically activated by the silylium cation resulted from the gold activation of the propargylsilane.



Scheme 1. Catalytic deoxygenative reported examples and working hypothesis.

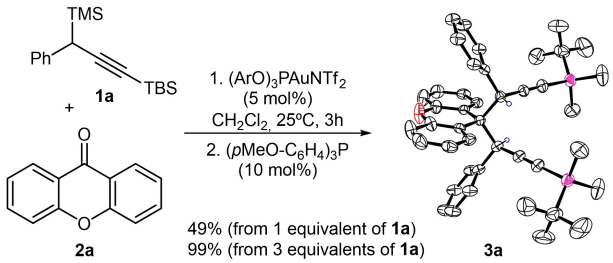
During the course of this investigation, we envisioned that xanthones could be suitable electrophiles for the mentioned gold-catalyzed propargylation reaction due to the special electronic nature of the carbonyl function. Xanthones, thioxanthones and their reduced derivatives xanthydrols and xanthenes, are natural occurring molecules[8] with interesting properties due to their structure, and have proved their versatility as chemosensors,[9] molecular switches,[10] pharmaceuticals,[11] organic dyes,[12] building blocks in material science,[13] catalysts,[14] etc.

Herein, we describe the first catalytic bispropargylation of a carbonyl compound (Scheme 1, bottom). With this purpose, xanthones and thioxanthones were propargylated, using propargylsilanes, in a gold-catalyzed, synergistic, diasteroselective and high yielding synthesis of 9,9-bispropargylxanthenes and thioxanthenes. Additionally, monopropargylated xanthydrol and thioxanthydrol derivatives can be isolated and non-symmetrically bispropargylated xanthenes are also accessible following either stepwise or one-pot procedures. Finally, in order to demonstrate the synthetic applicability of the reported methodology, other transformations have been achieved.

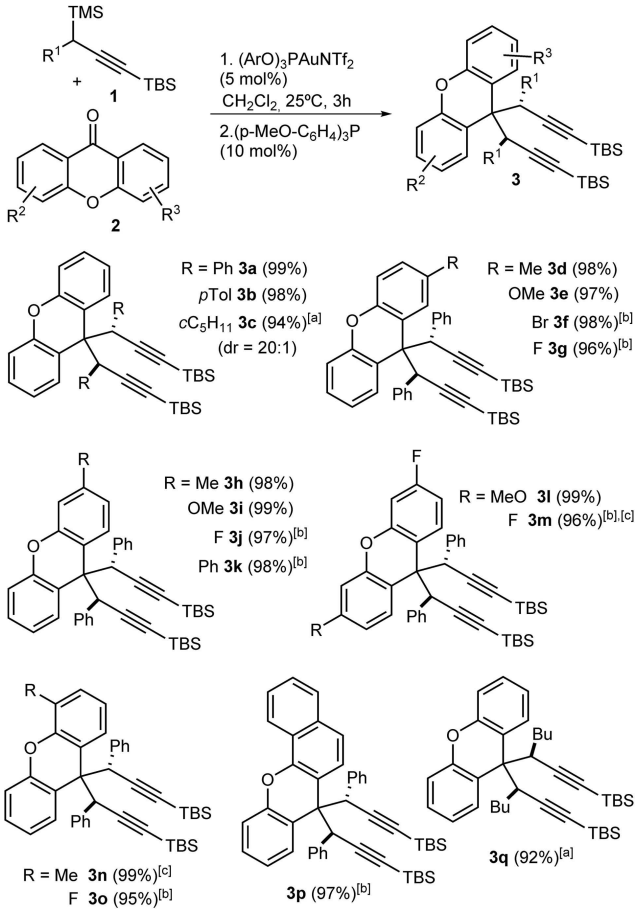
Results and Discussion

Taking into account our previously reported results for the propargylation reaction,[7] we initiated our investigations using [tris(2,4-di-*tert*-butylphenyl)-phosphite]gold(I) bistriflimidate [$(ArO)_3PAuNTf_2$] as the gold complex. Thus, adding a 5 mol% of the mentioned gold complex to a dichloromethane solution, at 25 °C, of equimolecular amounts of 3-phenyl-1-*tert*-butyldimethylsilyl-3-trimethylsilyl-1-propyne **1a** and xanthone **2a**, we observed the formation, after three hours of reaction, of a roughly 49% of bispropargylated xanthene **3a** (Scheme 2).[15] To our delight, starting from three equivalents of 3-phenyl-1-*tert*-butyldimethylsilyl-3-trimethylsilyl-1-propyne **1a**, xanthene **3a** was obtained in a quantitative yield, and as a single diastereoisomer. The structure of xanthene **3a** and the relative configuration of the stereocenters could be determined by an X-ray analysis of a crystal obtained from a dichloromethane/methanol solution.[16]

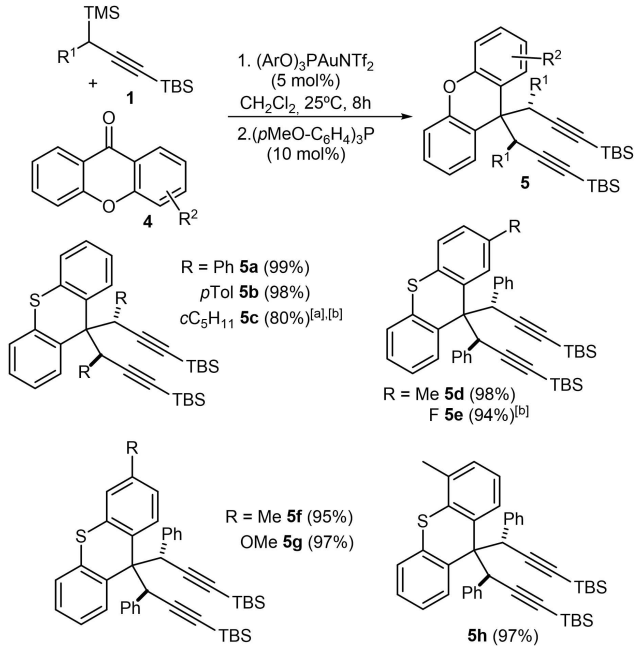
As the next step, we decided to test the scope of the reaction in terms of the substitution of the propargylsilanes **1**, (using three equivalents) and the two arene rings of the xanthone derivatives **2** (Scheme 3). As it can be observed, the gold-catalyzed double propargylation reaction occurs with total diastereoselectivity, in an almost quantitative yield, and it tolerates a wide nature of substitution patterns. In this sense, xanthene derivatives **3** with a large range in the substitution pattern of the arene rings could be obtained. Thus, bispropargylxanthenes with electron donating (**3d–e,h–i,l,n**) or electron-withdrawing groups (**3f–g,j,m,o**) and even a benzofused xanthene **3p** are accessible, in very high yield. It is worth to mention that, with the exception of the *ortho*-position, these substituents can appear at any position of the arene rings. On the other hand, the stereochemistry of the products might be explained through a possible electronic interaction of the arene ring with the xanthene skeleton, as both arenes face it. In addition to arene rings, the presence of aliphatic substituents at the propargylsilane is also tolerated (xanthenes **3c,q**). However, xanthene **3q**



Scheme 2. Preliminary results in the gold-catalyzed bispropargylation of xanthone **2a**. ORTEP view with thermal ellipsoids at the 25% level. For clarity, only the hydrogens of the stereocenters are kept. Ar = 2,4-di-*t*-butylphenyl.



Scheme 3. Bispropargylation of xanthones **2**. cC_5H_9 = cyclopentyl. [a] 16 h or [b] 6 h of reaction. [c] Reaction performed at 60 °C in 1,2-dichloroethane (DCE).



Scheme 4. Bispropargylation of thioxanthones **4**. [a] Reaction performed at 60 °C in DCE; [b] 16 h of reaction.

bearing butyl groups, emerged with a totally opposite diastereoselectivity compared to the rest of compounds.[17] Interestingly, no relevant differences were observed for a reaction performed at gram scale (3 mmol), resulting in the formation of 1.86 g (97%) of bispropargylxanthene **3 a**.

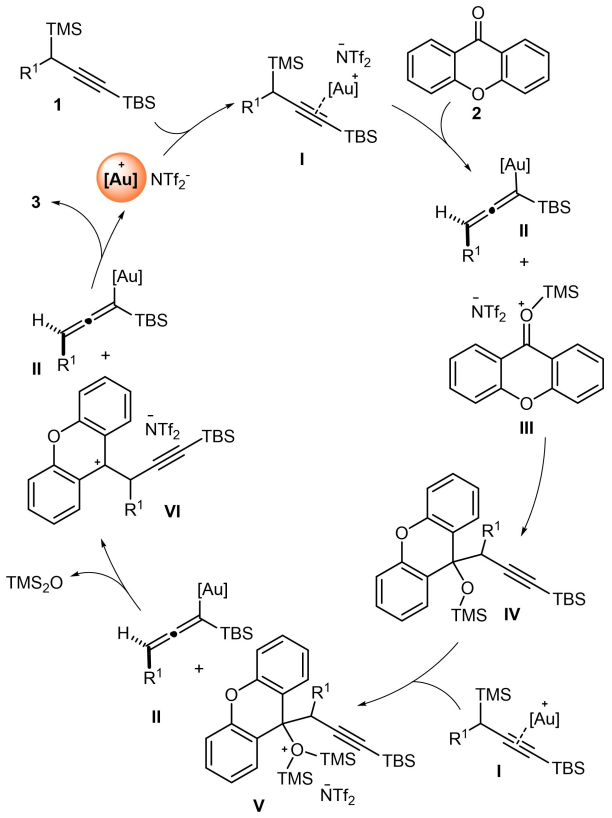
Inspired by these results we also envisioned the use of thioxanthone derivatives as starting materials in order to synthesize the corresponding bispropargylthioxanthene derivatives. Sulphur analogues of xanthenes have also demonstrated interesting properties, such as their pharmacological applicability.[18] Thus, we observed that a diastereoselective gold(I)-catalyzed deoxygenative bispropargylation of thioxanthone **4**, occurs under similar reaction conditions, although longer reaction times are required compared to the bispropargylation of their xanthone analogues (Scheme 4). Again, different substitution patterns in both, the arene rings of the thioxanthone **4** and the propargylsilane **1**, were tolerated.

Once the scope of both bispropargylations was analyzed, a mechanistic proposal could be envisioned and it is described in Scheme 5.

Thus, after formation of the σ-gold allenyl intermediate **II**,[7a] the reaction should initiate by a synergistic gold catalyzed monopropargylation of the carbonyl to form intermediate **IV**. Next, in a similar way to our previously described gold-catalyzed propargylations[7] or alkynylations,[4b,19] intermediate **IV** could be, again, synergystically activated by coordination of the trimethylsilyl cation. The energetic barrier for the elusive second propargylation addition could be overcome by the participation of the lone pair located at the oxygen (or sulphur) atom of the central ring to promote the $(TMS)_2O$ elimination and formation of the aromatic dibenzopyrilium cation **VI**.[20] In this sense, participation of pyrilium intermediate **VI**, could favor a new propargylation step by nucleophilic attack of intermediate **II** resulting in the formation of xanthene derivatives **3** (or **5**).

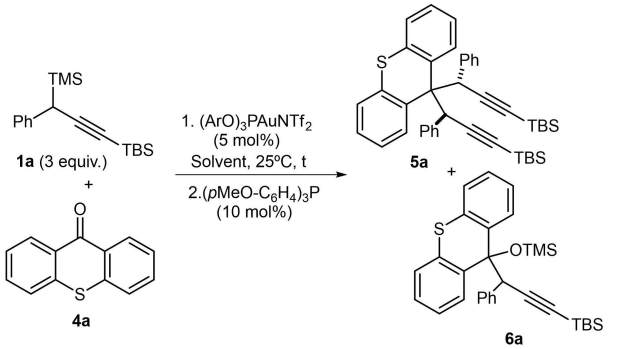
The presence of intermediate **IV** was confirmed by the isolation of propargylthioxanthydrol silyl ether **6 a**, from **4 a** and **1 a** (1.2 equiv.) under the standard reaction conditions, using shorter reaction time. In this sense, reaction time and solvent optimization for the gold-catalyzed monopropargylation reaction of thioxanthone **4 a**, gave rise to the partial or exclusive formation of propargylthioxanthydrol silyl ether **6 a** (Table 1).

Relevantly, from Table 1 it can be inferred that monopropargylated compound **6 a** could be formed as



Scheme 5. Mechanistic proposal for the formation of bispropargylxanthones **3**.

Table 1. Monopropargylation optimization.



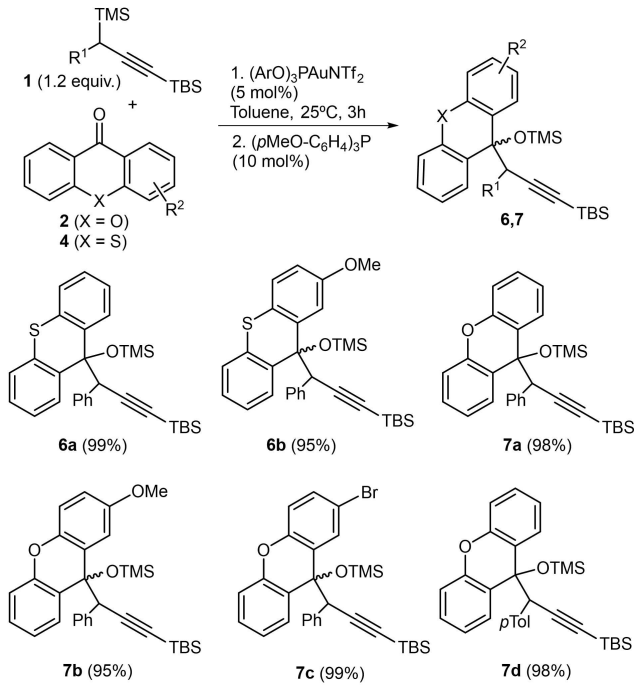
Entry	Solvent	Time	**5a**(%)[a]	**6a**(%)[a]
1	CH_2Cl_2	8 h	99	–
2	CH_2Cl_2	3 h	25	74
3	CH_2Cl_2	2 h	–	98
4	DCE	3 h	20	78
5	$CHCl_3$	3 h	< 5	95
6	Hexane	3 h	–	36
7	Toluene	3 h	–	99
8	CH_3CN	3 h	–	95
9	1,4-Dioxane	3 h	–	98

[a] Calculated by NMR with dibromomethane as internal standard.

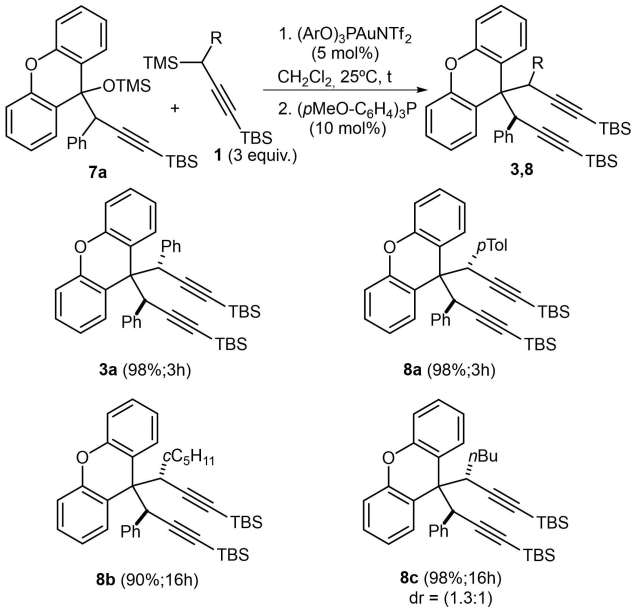
main product, either shortening the reaction time in dichloromethane (entries 2, 3) or through a solvent modification. Thus, other chlorinated solvents such as 1,2-dichloroethane or chloroform yield **6a** as mayor compound. However, hexane (entry 6) and toluene (entry 7), nonpolar solvents, give only **6a** in 36% and 99% yield respectively. On the other hand, acetonitrile (entry 8) or 1,4-dioxane (entry 9) also give rise to the exlusive formation of **6a**. These solvents, both polar and coordinating ones, could difficult the evolution from monopropargylated xanthydrol silyl ether **IV** intermediate to dibenzopyrilium intermediate **V** and the formation of the bispropargylated xanthene derivative. Taking these results into account, the use of toluene and 1.2 equivalents of **1**, allowed us to synthesize and isolate thioxanthydrol silyl ethers **6a,b**. (Scheme 6). Similar behavior was observed using xanthones **2** leading to the formation of their oxygen analogues **7**.

At this point, we decided to subject monopropargylated xanthydrol derivatives **7** to the standard reaction conditions for the synthesis of bispropargylated xanthenes **3** pursuing two main targets, as follows: i) to support the role of compounds **7** as reaction intermediates and ii) to open the access to non-symmetrically bispropargylated xanthenes. Both targets were satisfactorily achieved and the results are reported in Scheme 7.

Going one step further, non-symmetrically bispropargylated xanthene **8a** could also be synthesized, in a one-pot manner, without isolation of monopropargy-



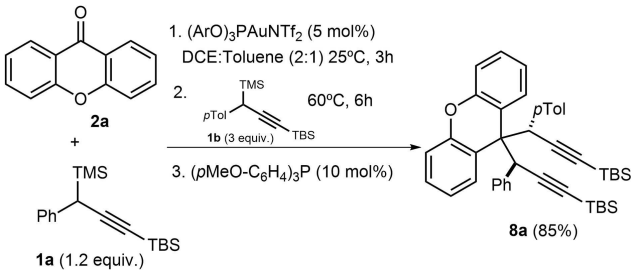
Scheme 6. Synthesis of monopropargylated xanthydrol silyl ethers.



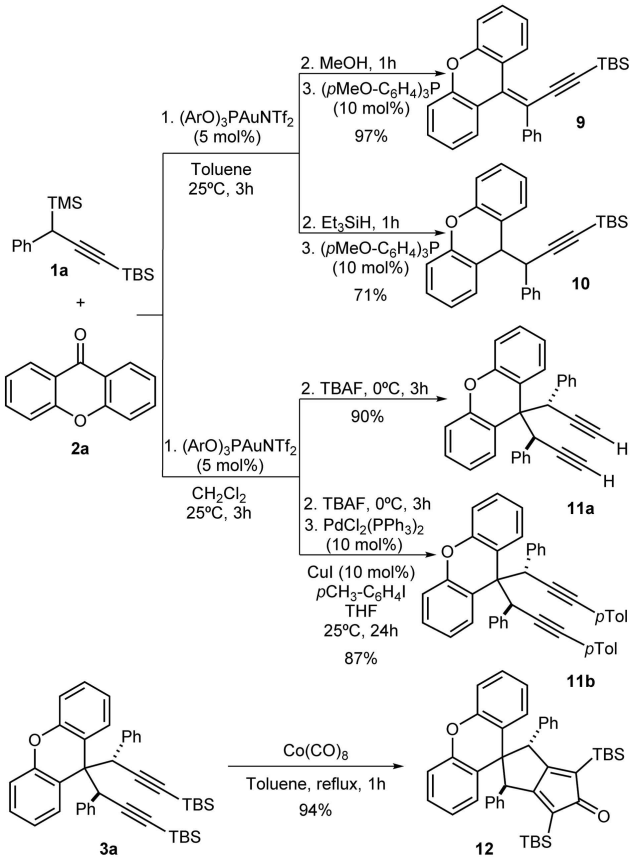
Scheme 7. Propargylation of xanthydrol silyl ethers **7**.

lated intermediate **7a**. This target could be achieved through a sequential addition of two different propargylsilanes, in a mixture of solvents (Scheme 8). It is worth to remark that these results, either stepwise or one-pot, open the door to expand the number of structures that could be easily synthesized.

Finally, as a demonstration of the utility of the gold-catalyzed mono- and bispropargylation of xanthones, a number of transformations of these compounds could be achieved, in most of the cases in a one-pot manner from the corresponding xanthone **2**. Thus, propargylxanthylidene **9** and propargylxanthene **10** could be obtained, in high yields, through an *in situ* elimination or reduction of the corresponding propargylxanthydrol silyl ether, using methanol or triethylsilyl hydride, respectively. (Scheme 9; *top*). On the other hand, in a one-pot procedure involving bispropargylation of xanthone **3a** followed by deprotection or consecutive deprotection-Sonogashira arylation steps, unsubstituted **11a** or arylsubstituted bispropargylxanthones **11b** could be synthesized



Scheme 8. One-pot synthesis of non-symmetrical xanthene **8a**.



Scheme 9. Propargylxanthene transformations.

(Scheme 9; *middle*). This procedure can be considered as complementary for the synthesis of non-accessible bispropargylxanthenes following gold-catalyzed conventional methodology.[21] Finally, spirocyclic xanthene **12** could be accessed through an intramolecular carbonylative [2+2+1] cycloaddition, of bispropargylxanthene **3a**, using cobalt octacarbonyl (Scheme 9; *bottom*).

Conclusion

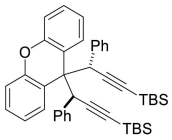
In summary, we describe here a gold-catalyzed double propargylation of privileged structures as xanthones and thioxantones. This reaction represents a procedure for a catalytic deoxygenative bispropargylation of carbonyl compounds. Xanthone and thioxanthone derivatives are synergistically activated by a silyl group facilitating, in two consecutive steps and in a diastereoselective way, the catalytic nucleophilic attack of the σ-gold allenyl intermediate generated from the corresponding propargylsilanes. Propargylxanthydrol silyl ethers, identified as intermediates for this bispropargylation process, can also be isolated and submitted to a second propargylation step, allowing the formation of non-symmetrical bispropargylated xanthenes, either stepwise or in a one-pot procedure.

Finally, due to the interest of the xanthene derivatives in different fields -from pharmacology to materials science- several transformations from eliminations to substitutions could be *in-situ* achieved from the corresponding xanthones. In addition, spirocyclic compounds are also accessible through a carbonylative [2 + 2 + 1] formal cycloaddition.

Experimental Section

Experimental Procedure for the Gold(I)-Catalyzed Bispropargylation Reaction of Xanthone Derivatives

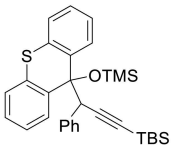
To a solution of 0.20 mmol of the corresponding xanthone **2** or thioxanthone **4**, in 1 mL of dry dichloromethane at 25 °C and under argon atmosphere, 0.6 mmol of the propargylsilane **1** and 11.2 mg of the gold catalyst (5 mol%), were sequentially added. The reaction mixture was stirred for 3 h for xanthones **2** (6 h for products **3f–g,j–k,m,o–p** or 16 h for **3c–q**) and 8 h for thioxanthones **4** (16 h for products **5c,e**), at 25 °C (60 °C for products **3m** and **5c**), upon starting material disappearance. Finally, 8.2 mg (0.02 mmol, 10 mol%) of (pMeO-C_6H_4)$_3$P were added for catalyst deactivation, and the solvent was removed under vacuum. Flash column chromatography through silica gel of the residue afforded the corresponding 9,9-bispropargylxanthenes **3**, and 9,9-bispropargylthioxanthenes **5**.



((3*S,3'*S**)-(9*H*-Xanthene-9,9-diyl)bis(3-phenylprop-1-yne-3,1-diyl))bis(*tert*-butyldimethylsilane) (3a)**: Yield = 99%, 127 mg. White solid; mp = 151.5–153.5 °C. R_f (SiO_2) = 0.20 (Hexane : Ethyl acetate, (100:1)). ^{1}H-NMR (300 MHz, $CDCl_3$, 25 °C, TMS): δ (ppm) = 8.79–8.74 (m, 2H), 7.20–7.07 (m, 4H), 7.02–6.92 (m, 2H), 6.86 (tt, $J_{(H,H)}$ = 6.4, 1.6 Hz, 4H), 6.67–6.60 (m, 4H), 6.56–6.49 (m, 2H), 5.19 (s, 2H), 1.11 (s, 18H), 0.27 (s, 6H), 0.26 (s, 6H). ^{13}C-NMR (75 MHz, $CDCl_3$, 25 °C): δ (ppm) = 151.3 (2×C), 137.9 (2×C), 129.8 (4×CH), 128.7 (4×CH), 127.2 (4×CH), 126.7 (2×CH), 121.7 (2×CH), 120.7 (2×C), 116.2 (2×CH), 108.3 (2×C), 89.3 (2×C), 50.3 (2×CH), 50.1 (C), 26.5 (6×CH_3), 17.1 (2×C), −4.4 (4×CH_3). HRMS (EI) for $C_{43}H_{50}NaOSi_2$ [M + Na]: Calc.: 661.3292; found: 661.3269.

General Protocol for the Selective Monopropargylation Reaction of Xanthone Derivatives

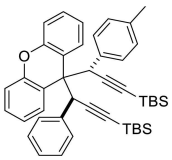
To a solution of 0.20 mmol of the corresponding xanthone **2**, or thioxanthone **4**, in 1 mL of dry toluene at 25 °C under argon atmosphere, 0.24 mmol of the propargylsilane **1** (1.2 equiv.) and 11.2 mg of the gold catalyst (5 mol%) were sequentially added. The reaction mixture was stirred for 3 h. Finally, 8.2 mg (0.02 mmol, 10 mol%) of (pMeO-C_6H_4)$_3$P were added for catalyst deactivation, and the solvent was removed under vacuum. Flash column chromatography through deactivated aluminium oxide of the residue afforded the corresponding 9-propargylxanthydrols **7** or 9-propargylthioxanthydrol silyl ethers **6**, respectively. Similar result was obtained for a reaction performed at a 3 mmol scale, obtaining 1.47 g (98% yield) of compound **7a**.



***Tert*-butyldimethyl(3-phenyl-3-(9-((trimethylsilyl)oxy)-9*H*-thioxanthen-9-yl)prop-1-yn-1-yl)silane (6a)**: Yield = 99%, 102 mg. Colorless oil. R_f (SiO_2) = 0.05 (Hexane : Ethyl acetate, (200:1)). ^{1}H-NMR (300 MHz, $CDCl_3$, 25 °C, TMS): δ (ppm) = 7.91–7.77 (m, 1H), 7.69 (dd, $J_{(H,H)}$ = 8.0, 1.5 Hz, 1H), 7.32–7.23 (m, 2H), 7.23–7.14 (m, 4H), 7.13–7.08 (m, 1H), 7.03 (dd, $J_{(H,H)}$ = 8.3, 7.0 Hz, 2H), 6.76–6.66 (m, 2H), 4.21 (s, 1H), 0.99 (s, 9H), 0.17 (s, 3H), 0.12 (s, 3H), 0.00 (s, 9H).^{13}C-NMR (75 MHz, $CDCl_3$, 25 °C): δ (ppm) = 136.7 (C), 136.6 (2×C), 135.2 (C), 130.3 (2×CH), 130.1 (C), 130.0 (CH), 129.7 (CH), 127.7 (CH), 127.6 (CH), 127.1 (2×CH), 127.0 (CH), 125.0 (CH), 124.7 (CH), 124.6 (CH), 124.4 (CH), 106.6 (C), 87.3 (C), 79.7 (C), 53.7 (CH), 26.4 (3×CH_3), 16.9 (C), 2.2 (3×CH_3), −4.4 (CH_3), −4.5 (CH_3). HRMS (EI) for $C_{31}H_{38}NaOSSi_2$ [M + Na]: Calc.: 537.2074; found: 537.2068.

One-Pot Procedure for the Synthesis of Non-Symmetrical 9,9-Bispropargylxanthenes 8

In a Schlenck tube under argon atmosphere, xanthone **2a** (39.2 mg, 0.20 mmol) and propargylsilane **1a** (72.5 mg, 0.24 mmol) were dissolved in a mixture of 0.6 mL of dry 1,2-dichloroethane and 0.3 mL of dry toluene, at 25 °C. Then, 11.2 mg of the gold catalyst (5 mol%) were added, and the reaction mixture was stirred for 3 h. After that time, propargylsilane **1b** (190 mg, 0.6 mmol) was added in one portion, and the mixture was stirred at 60 °C for 6 h. Finally, 8.2 mg (0.02 mmol, 10 mol%) of (pMeO-C_6H_4)$_3$P were added and the solvent removed under vacuum. After the corresponding column purification, 111 mg (85%) of 9,9-bispropargylxanthene 8a were obtained.

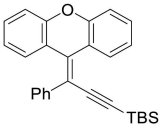


***Tert*-Butyl((*S**)-3-(9-((*S**)-3-(*Tert*-Butyldimethylsilyl)-1-(*p*-Tolyl)Prop-2-yn-1-yl)-9*H*-Xanthen-9-yl)-3-Phenylprop-1-yn-1-yl)Dimethylsilane (8a)**: Yield = 85%, 111 mg (From xanthone 2a). White solid; mp = 113.1–115.0 °C. R_f (SiO_2) = 0.21 (Hexane : Ethyl acetate, (100:1)). ^{1}H-NMR (300 MHz, $CDCl_3$, 25 °C, TMS): δ (ppm) = 8.78 (dd, $J_{(H,H)}$ = 7.2, 2.6 Hz, 1H), 8.71 (dd, $J_{(H,H)}$ = 7.2, 2.6 Hz, 1H), 7.12 (ddt, $J_{(H,H)}$ = 10.2, 7.2, 3.8 Hz, 4H), 6.96 (t, $J_{(H,H)}$ = 7.3 Hz, 1H), 6.85 (dd, $J_{(H,H)}$ = 8.3, 6.6 Hz, 2H), 6.67 (d, $J_{(H,H)}$ = 8.2 Hz, 2H), 6.62–6.57 (m, 2H), 6.53 (dd, $J_{(H,H)}$ = 7.7, 2.5 Hz, 4H), 5.18 (s, 1H), 5.16 (s, 1H), 2.11 (s, 3H), 1.10 (s, 9H), 1.09 (s, 9H) 0.26 (s, 6H), 0.25 (s, 6H). ^{13}C-NMR (75 MHz, $CDCl_3$, 25 °C): δ (ppm) = 151.3 (C), 138.0 (C), 136.1

(C), 134.9 (C), 129.8 (2×CH), 129.7 (2×CH), 128.7 (CH), 128.6 (CH), 128.6 (CH), 128.5 (CH), 128.0 (3×CH), 127.1 (2×CH), 126.6 (CH), 121.7 (CH), 121.6 (CH), 120.9 (C), 120.8 (C), 116.1 (CH), 116.0 (C), 108.7 (C), 108.3 (C), 89.2 (C), 89.0 (C), 50.6 (CH), 50.0 (C), 49.6 (CH), 26.5 (6×CH_3), 21.0 (CH_3), 17.1 (2×C), −4.4 (4×CH_3). HRMS (EI) for $C_{44}H_{52}NaOSi_2$ [M+Na]: Calc.: 675.3454; found: 675.3450.

One-Pot Procedure for the Synthesis of Xanthylidene Derivative 9

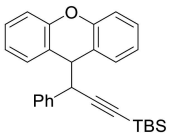
Following the procedure described for the selective monopropargylation of xanthone derivatives, a 0.20 mmol solution of xanthydrol silyl ether **7a** in toluene (1 mL) was prepared reacting propargylsilane **1a** and xanthone **2a** in the presence of the gold catalyst. Then, before deactivation of the complex, 162 µL (4 mmol, 20 equiv.) of MeOH were added in one portion, and the mixture was stirred for an additional period of 1 h. Finally, 8.2 mg (0.02 mmol, 10 mol%) of (pMeO-C_6H_4)$_3$P were added as deactivating agent and the solvent was removed under vacuum. Flash column chromatography of the residue through silica gel afforded the corresponding xanthylidene derivative **9** in a 97% yield (79 mg).



***Tert*-butyldimethyl(3-phenyl-3-(9*H*-xanthen-9-ylidene)prop-1-yn-1-yl)silane (9)**: Yield = 97%, 79 mg. White solid, mp = 127.1–129.0 °C. R_f (SiO_2) = 0.21 (Hexane : Ethyl acetate, (100:1)). ^{1}H-NMR (300 MHz, $CDCl_3$, 25 °C, TMS): δ (ppm) = 8.77 (dd, $J_{(H,H)}$ = 8.0, 1.6 Hz, 1H), 7.42–7.22 (m, 7H), 7.17 (tdd, $J_{(H,H)}$ = 4.1, 3.4, 1.4 Hz, 3H), 6.69 (dd, $J_{(H,H)}$ = 4.2, 2.9 Hz, 2H), 1.00 (s, 9H), 0.16 (s, 6H). ^{13}C-NMR (75 MHz, $CDCl_3$, 25 °C): δ (ppm) = 153.5 (C), 153.1 (C), 140.4 (C), 132.4 (C), 130.0 (2×CH), 129.8 (CH), 129.4 (CH), 128.9 (CH), 128.5 (2×CH), 127.8 (CH), 127.4 (CH), 124.2 (C), 123.0 (C), 122.4 (CH), 122.3 (CH), 117.4 (C), 116.7 (CH), 116.3 (CH), 108.1 (C), 101.3 (C), 26.4 (3×CH_3), 17.1 (C), −4.6 (2×CH_3). HRMS (EI) for $C_{28}H_{28}NaOSi$ [M+Na]: Calc.: 431.1802; found: 431.1803.

One-Pot Procedure for the Synthesis of 9-Propargylxanthene Derivative 10

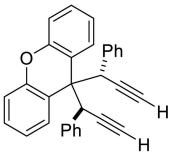
Following the procedure described for the selective monopropargylation of xanthone derivatives, a 0.20 mmol solution of xanthydrol silyl ether **7a** in toluene (1 mL) was prepared from propargylsilane **1a** and xanthone **2a**. Then, 96 µL (0.6 mmol, 3 equiv.) of Et_3SiH were added in one portion, and the mixture was stirred for an additional period of 1 h. Finally, 8.2 mg (0.02 mmol, 10 mol%) of (p-MeO-C_6H_4)$_3$P were added and the solvent was removed under vacuum. Flash column chromatography of the residue through silica gel afforded 58 mg of the corresponding 9-propargylxanthene derivative **10** in a 71% yield.



***Tert*-butyldimethyl(3-phenyl-3-(9*H*-xanthen-9-yl)prop-1-yn-1-yl)silane (10)**: Yield = 71%, 58 mg. White solid, mp = 87.7–89.4 °C. R_f (SiO_2) = 0.30 (Hexane : Ethyl acetate, (100:1)). ^{1}H-NMR (300 MHz, $CDCl_3$, 25 °C, TMS): δ (ppm) = 7.32 (dd, $J_{(H,H)}$ = 7.6, 1.7 Hz, 1H), 7.21 (ddt, $J_{(H,H)}$ = 7.0, 5.3, 1.7 Hz, 3H), 7.17–7.09 (m, 2H), 7.07–6.87 (m, 5H), 6.77 (dt, $J_{(H,H)}$ = 7.0, 1.5 Hz, 2H), 4.37 (d, $J_{(H,H)}$ = 4.8 Hz, 1H), 4.00 (d, $J_{(H,H)}$ = 4.7 Hz, 1H), 0.93 (s, 9H), 0.14 (s, 3H), 0.10 (s, 3H). ^{13}C-NMR (75 MHz, $CDCl_3$, 25 °C): δ (ppm) = 153.0 (C), 152.9 (C), 137.5 (CH), 129.7 (CH), 129.5 (CH), 128.9 (2×CH), 128.2 (2×CH), 127.8 (2×CH), 127.2 (CH), 122.6 (2×CH), 121.9 (C), 121.8 (C), 116.2 (CH), 116.1 (CH), 106.5 (C), 88.0 (C), 49.2 (CH), 46.8 (CH), 26.3 (3×CH_3), 16.7 (C), −4.5 (2×CH_3). HRMS (EI) for $C_{28}H_{31}OSi$ [M+H]: Calc.: 411.2144; found: 411.2140.

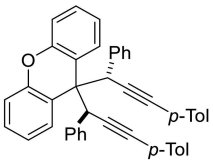
Experimental Procedure for the One-Pot Synthesis of 9,9-Propargylxanthene Derivatives 11

Following the described methodology for the bispropargylation reaction, after 3 h of reaction the mixture was cooled down to 0 °C, and 1 mL of THF was added. Then, 0.5 mmol of TBAF (0.5 mL, 1 M in THF) were added dropwise. After complete addition, the cooling bath was removed and the mixture stirred at room temperature for and additional period of 3 h. The crude was diluted with EtOAc, washed with water, dried over Na_2SO_4, filtered and the solvents were removed under vacuum. Flash column chromatography over silica gel afforded 74 mg of pure compound **11a** (90% yield). For the in-situ Sonogashira reaction, 4-iodotoluene (131 mg, 0.6 mmol, 3 equiv.), Pd(PPh_3)$_2$$Cl_2$ (5.6 mg, 4 mol%) and CuI (1 mg, 2 mol%) were added before dropping the TBAF solution. After complete addition, the cooling bath was removed and the mixture stirred at room temperature for and additional period of 6 h. The crude was diluted with EtOAc, washed with water, dried over Na_2SO_4, filtered and the solvents were removed under vacuum. Flash column chromatography over silica gel afforded 74 mg of compound **11b** (87% yield).



9,9-Bis((*S)-1-phenylprop-2-yn-1-yl)-9*H*-xanthene (11a)**: Yield = 90%, 74 mg. White solid, mp = > 174.0 °C (dec.).R_f (SiO_2) = 0.18 (Hexane : Ethyl acetate, (40:1)). ^{1}H-NMR (300 MHz, $CDCl_3$, 25 °C, TMS): δ (ppm) = 8.81–8.51 (m, 2H), 7.18 (q, $J_{(H,H)}$ = 5.1, 4.7 Hz, 4H), 6.98 (t, $J_{(H,H)}$ = 7.3 Hz, 2H), 6.87 (t, $J_{(H,H)}$ = 7.6 Hz, 4H), 6.63 (d, $J_{(H,H)}$ = 7.8 Hz, 4H), 6.59–6.50 (m, 2H), 5.19 (d, $J_{(H,H)}$ = 2.8 Hz, 2H), 2.71 (d, $J_{(H,H)}$ = 2.8 Hz, 2H). ^{13}C-NMR (75 MHz, $CDCl_3$, 25 °C): δ (ppm) = 151.3 (2×C), 137.5 (2×C), 129.7 (4×CH), 128.9 (2×CH), 128.6 (2×CH), 127.3 (4×CH), 126.8 (2×CH), 122.0 (2×CH),

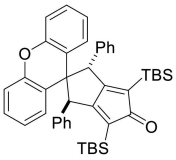
120.5 (2×C), 116.3 (2×CH), 85.5 (2×C), 74.4 (2×CH), 49.6 (C), 48.8 (2×CH). HRMS could not be obtained. Unstable compound.



9,9-Bis((*S)-1-Phenyl-3-(*p*-Tolyl)Prop-2-yn-1-yl)-9H-Xanthene (11b):** Yield = 87%, 103 mg. Yellowish oil. R_f (SiO_2) = 0.25 (Hexane : Ethyl acetate, (20:1)). ^{1}H-NMR (300 MHz, $CDCl_3$, 25 °C, TMS): δ (ppm) = 8.77–8.60 (m, 2H), 7.54 (d, $J_{(H,H)}$ = 8.0 Hz, 4H), 7.25–7.09 (m, 8H), 7.03–6.92 (m, 2H), 6.87 (t, $J_{(H,H)}$ = 7.5 Hz, 4H), 6.75–6.64 (m, 4H), 6.60–6.49 (m, 2H), 5.41 (s, 2H), 2.40 (s, 6H). ^{13}C-NMR (75 MHz, $CDCl_3$, 25 °C): δ (ppm) = 151.3 (2×C), 138.3 (2×C), 138.2 (2×C), 131.7 (5×CH), 129.8 (3×CH), 129.3 (5×CH), 128.7 (2×CH), 128.6 (2×CH), 127.2 (3×CH), 126.7 (2×CH), 122.0 (2×CH), 121.0 (2×C), 120.9 (2×C), 116.1 (2×CH), 90.5 (2×C), 85.9 (2×C), 51.0 (C), 50.0 (2×CH), 21.7 (2×CH_3). HRMS could not be obtained. Unstable compound.

Experimental Procedure for the Synthesis of Spirocyclopentadienone Derivative 12

To a refluxing toluene solution (30 mL, 0.005 M) of 9,9-bispropargylxanthene **3a** (96 mg, 0.15 mmol) under nitrogen atmosphere, a toluene solution (20 mL) of freshly sublimated dicobalt octacarbonyl (69 mg, 0.20 mmol) was added dropwisely over 30 minutes. The resulting mixture was refluxed for an additional period of 1 h. Then, the black precipitate formed was removed by filtration through a small pad of silica gel, using hexane as eluent. After solvent removal under reduced pressure, the residue was purified by flash silica gel column chromatography to afford 116 mg (94%) of spirocyclopentadienone derivative **12**.



(1*S,3*S**)-4,6-Bis(*tert*-butyldimethylsilyl)-1,3-diphenyl-1*H*-spiro[pentalene-2,9′-xanthen]-5(3*H*)-one (12)**: Yield = 94%, 116 mg. Bright yellow solid, mp = > 200.0 °C (dec.). R_f (SiO_2) = 0.20 (Hexane : Ethyl acetate, (20:1)). ^{1}H-NMR (300 MHz, $CDCl_3$, 25 °C, TMS): δ (ppm) = 7.16-6.99 (m, 10H), 6.84 (dd, $J_{(H,H)}$ = 8.2, 1.4 Hz, 2H), 6.81–6.72 (m, 6H), 4.66 (s, 2H), 0.85 (s, 18H), −0.12 (s, 6H), −0.28 (s, 6H). ^{13}C-NMR (75 MHz, $CDCl_3$, 25 °C): δ (ppm) = 212.2 (C), 180.8 (2×C), 150.5 (2×C), 139.0 (2×C), 130.3 (4×CH), 129.0 (2×CH), 128.2 (2×CH), 128.1 (4×CH), 127.3 (2×CH), 125.8 (2×C), 123.0 (2×C), 122.0 (2×CH), 116.5 (2×CH), 61.4 (2×CH), 58.9 (C), 27.6 (6×CH_3), 18.3 (2×C), −4.3 (2×CH_3), −4.7 (2×CH_3). HRMS (EI) for $C_{44}H_{50}NaO_2Si_2$ [M + Na]: Calc.: 689.3242; found: 689.3239.

Acknowledgements

Authors acknowledge support by the Spanish Government AEI (PID2019-107469RB-I00/AEI/10.13039/501100011033). S. F. and D. A. also thanks for respective predoctoral fellowships (FPU-2016-07221 and BES-2017-079853, respectively). Authors would like to acknowledge the technical support provided by Servicios Científico-Técnicos de la Universidad de Oviedo.

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[15] A 10 mol% of a phosphine was added at the end of the reaction to inactivate gold catalyst minimizing secondary reactions and decomposition issues.
[16] Crystallographic data for compound **3a** (**CCDC-2164615**) can be accessed free of charge from TheCambridge Crystallographic Data Centre via www.ccdc.cam.ac.uk/data_request/cif.
[17] For compounds **3c** and **3q**, lacking of the arene rings, diastereoselectiviy could be affected by the sterical hindrance. Thus, for compound **3q**, the flexibility of the butyl group permits it to find a more favorable accommodation in the opposite diastereoisomer whereas with the use of R = *c*C_5H_9 (**3c**), a bulkier group, in the corresponding propargylsilane, the reaction follows the general diastereoselection.
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[20] The use of thioxanthone dioxide –compound lacking of the lone electron pair– did not resulted in the formation of the bispropargylated analogue as only monopropargyl silyl ether **13** was obtained (*See supporting information*).
[21] Propargylsilanes with hydrogen or aryl group at the acetylenic position did not perform gold-catalyzed propargylation reactions. See ref. 7.