Cavity-controlled coordination of square planar metal complexes and substrate selectivity by NHC-capped cyclodextrins (ICyDs)

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Dr. Jorge Meijide Suárez, Dr. Olivia Bistri-Aslanoff, Dr. Sylvain Roland*, Prof. Dr. Matthieu Sollogoub*

Sorbonne Université, CNRS, Institut Parisien de Chimie Moléculaire (IPCM), UMR 8232, 4, place Jussieu, 75005 Paris, France

emails : sylvain.roland@sorbonne-universite.fr, matthieu.sollogoub@sorbonne-universite.fr

Twitter @SollogoubM

Web: https://ipcm.fr/article665.html

***Abstract*:** Encapsulation of a metal center inside the cavity of a cyclodextrin (CD) allows the control of the possible coordination modes for the metal depending on the nature and size of the cavity. We show here that the formation of encapsulated square planar Au^{III} and Pd^{II} complexes with CD-*N*-heterocyclic carbene (NHC) ligands, is only possible in the largest β- and γ-CD cavities. In the case of α-CD-derived ligands and Pd^{II}, an unexpected reversal of the NHC ligand was observed. These extraverted or introverted conformations of metal complexes were carefully studied by NMR and their different behaviors depending on the cavity could be revealed. The size of the CD cavity was also found to have a significant effect on the ability of Au^{I} to be oxidized into Au^{III}. Furthermore, in the Pd^{II}-catalyzed nucleophilic allylation of aldehydes, the β-CD-derived ligand was able to discriminate different substrates from a mixture according to their size, leading to a significantly favored reaction with the smallest substrate.

Introduction

Inspired by metalloproteins, encapsulated metal complexes have been developed to induce selective reactions and they constitute today an intense field of activity.[1] Different cages, capsules, and cavities have been used as molecular containers. Among these, cyclodextrins (CDs) represent an important and historical class of cavities. CDs are cyclic oligosaccharides composed of 6, 7 or 8 glucopyranoside units which form α-, β- and γ-CDs respectively. They are naturally occurring and readily available in large quantities. In the 1950's Cramer already envisaged them as enzyme mimics owing to their characteristic hydrophobic cavity.[2] Furthermore, metal centers have been appended to these cavities,[3,4] and Breslow proposed the concept of "artificial enzyme" for such metallated CDs.[5,6] Since then, CDs have been used as ligands as such,[7] or after functionalization with phosphorus,[8,9] nitrogen,[10] sulfur[11] or carbon[12] atoms to coordinate the metal. In all these cases, the metal was placed at the verge of the cavity so as to leave it free to interact either with a ligand or with a substrate.

Sometime ago, we uncovered a family of *N*-heterocyclic-carbene (NHC)-capped CDs, that we called **ICyD**, that form encapsulated complexes of coinage metals (Cu^{I}, Ag^{I}, Au^{I}) with α, β, or γ-CDs (Figure 1).[13] This family of ligands stands out from those previously reported as it places the metal unit in the center of the cavity and not at the entrance. This situation induced original interactions with

inwardly oriented protons that we studied in detail.[14] In particular, the presence of the metal inside the cavity is easily detectable by NMR as it produces a deshielding of H^5 protons which point towards the metal center. These interactions were used to map the shape of the cavity.[15]

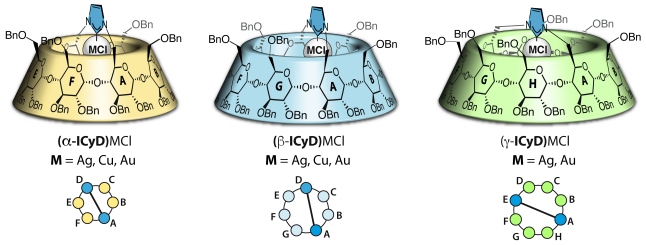
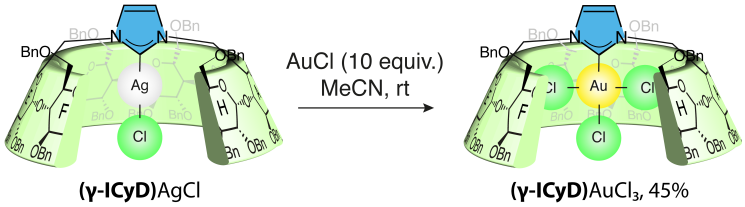


Figure 1. α-, β- and γ-ICyD-based coinage metal complexes.

We also used these complexes to operate catalytic reactions and demonstrated that the shapes of the cavities of α-, β- or γ-CD-ICyDs were different[15] and could induce cavity-dependent stereo-[13,15,16,17] regio-[18] and chemoselectivities,[19] as well as changes in the course of reactions,[13,15,16] and stabilization of reactive species.[19] We therefore also wondered if the structure/shape of the CD cavity could affect the coordination modes of encapsulated metal complexes. So far, our studies focused on group 11 metals exhibiting linear coordination (Cu^I, Ag^I, and Au^I). As a logical development, the exploration of other types of coordinations was considered and the introduction of classical square planar complexes in the cavity of **ICyD** ligands was investigated. Phosphane and other P(III) ligands have been extensively used to associate metal complexes with CD cavities,[8,9,20] and CD-phosphane Pd^{II}(allyl) complexes have also been reported.[8,9,10,21] By comparison, examples with NHC ligands associated with CDs or other cavities are scarce.[22] One of the particular features of **ICyD** CD-NHC ligands is their ability to coordinate the metal deep inside the CD cavity. We anticipated that this property may increase the interactions between the first coordination sphere of the metal and the second coordination sphere, i.e. the CD cavity, in metal complexes of higher coordination number and therefore influence their properties.

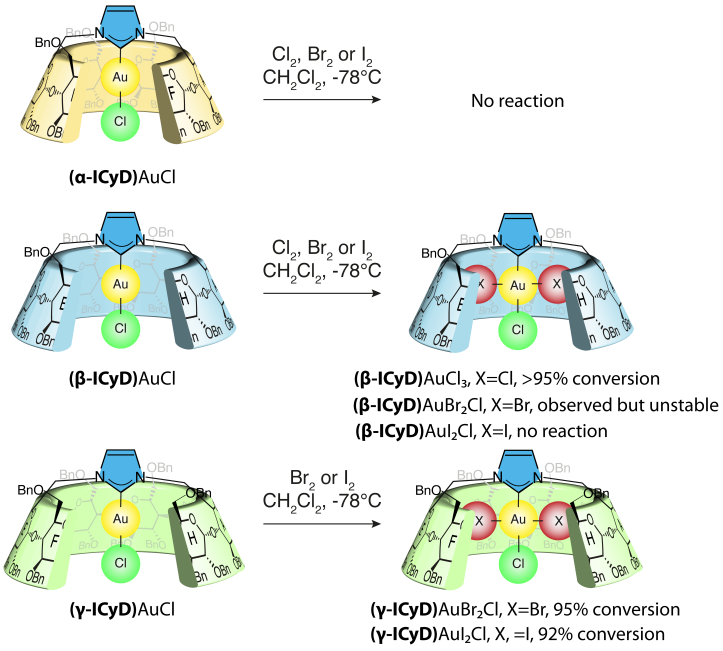
Results and Discussion

This work actually started with the serendipitous observation that treatment of the γ-CD-derived (**γ-ICyD**)AgCl complex with an excess of gold(I) chloride led to the isolation of the gold(III) complex (**γ-ICyD**)$AuCl_3$ likely resulting from transmetallation and subsequent disproportionation of the intermediate gold(I) complex (Scheme 1). (**γ-ICyD**)$AuCl_3$ was characterized by NMR and mass spectrometry. ^{13}C NMR data in acetone-d_6 showed a typical chemical shift of 143 ppm for the quaternary $C_{carbene}$, 30 ppm upfield compared to its Au^I counterpart[15] which is consistent with previous literature reports of NHC–$AuCl_3$ complexes.[23] A cross correlation between the $C_{carbene}$ and the imidazole backbone protons was also observed by HMBC (See SI). Hence, this unexpected formation of a Au^{III} complex in the largest γ-CD cavity opened new perspectives for studying the structure and properties of new metal complexes of higher coordination numbers embedded in a cavity of CD–NHC ligands.



Scheme 1. Serendipitous formation of a square planar complex inside a γ-CD.

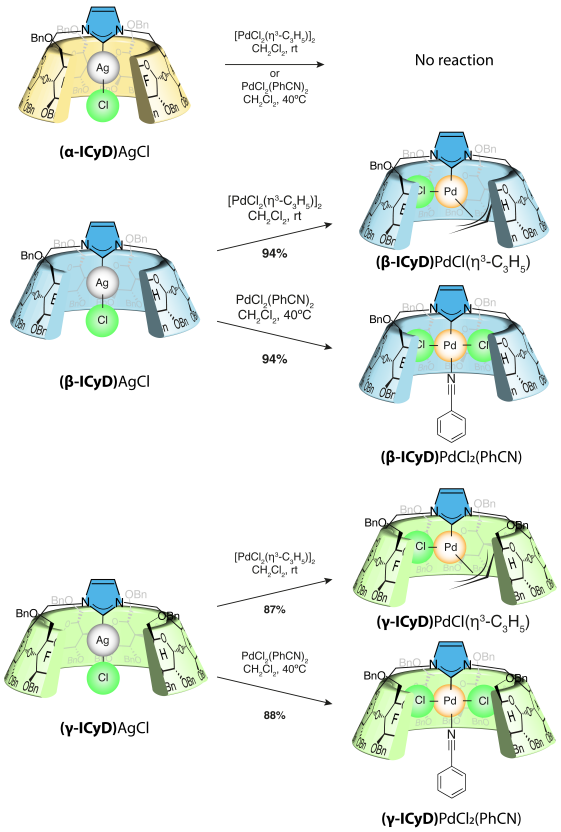
In a first series of experiments, we investigated the dihalogen-mediated oxidation of (**ICyD**)AuCl complexes into the corresponding Au^{III} complexes.[23,24] The three complexes (**α-ICyD**)AuCl, (**β-ICyD**)AuCl and (**γ-ICyD**)AuCl were treated with Cl_2, Br_2 and I_2 in CH_2Cl_2 at –78 °C (Scheme 2). After evaporation to dryness, the crude reaction mixtures were analyzed by ^1H NMR. The results demonstrate the determinant role of the cavity in controlling the oxidation of the Au^I complexes. Interestingly, no oxidation occurred in the smaller cavity of **α-ICyD**, while the larger **β-ICyD** allowed reaction with Cl_2 and Br_2, although in this last case the product was unstable in solution. Interestingly, no reaction occurred with I_2. Finally, in the largest **γ-ICyD** cavity, oxidation of Au^I was equally efficient with Br_2 and I_2 leading to the corresponding $AuBr_2Cl$ and AuI_2Cl complexes with 95 and 92% conversion respectively, which were both found stable in solution. The ability to oxidize Au^I into Au^{III} is therefore directly linked to the ability of the CD cavity to accommodate and stabilize the additional halogens to ligand the metal. (Scheme 2)



Scheme 2. Oxidation of **(ICyD)AuCl** complexes with dihalogens.

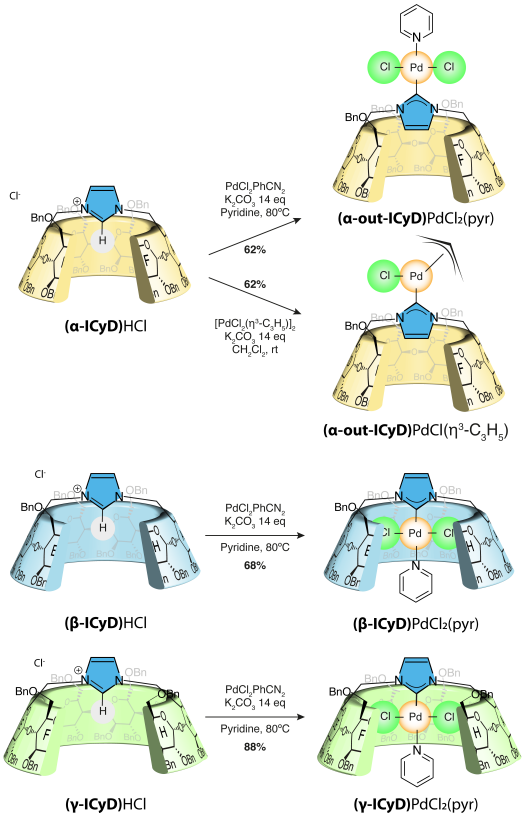
This access to square planar complexes prompted us to study Pd^{II} which also adopts this geometry and which could expand the scope of catalytic reactions that could benefit from encapsulation inside the CD cavities. To synthesize the Pd^{II} complexes, we first investigated transmetalation of the silver complexes **(ICyD)**AgCl with either $[Pd(\eta^3\text{-allyl})Cl_2]_2$ or $PdCl_2(PhCN)_2$.[25] This silver route was previously shown to be suitable for the preparation of CD-based **(ICyD)**Au^I and **(ICyD)**Cu^I complexes from (**ICyD**)AgCl.[15] Similarly, the method was found efficient for introducing a square planar palladium

center in both **β-ICyD** and **γ-ICyD** ligands, having the two largest cavities. Starting from either (**β-ICyD**)AgCl or (**γ-ICyD**)AgCl, and using both Pd complexes, the corresponding complexes (**β-ICyD**)$PdCl_2$(PhCN), (**β-ICyD**)PdCl(η^3-allyl), (**γ-ICyD**)$PdCl_2$(PhCN) and (**γ-ICyD**)PdCl(η^3-allyl) were obtained in 87-94% yields after silica gel purification. In stark contrast, but not unexpectedly, when the method was applied to (**α-ICyD**)AgCl having the smallest cavity among the three ligands, no trace of square planar Pd^{II} complex was obtained. (Scheme 3)



Scheme 3. Preparation of **ICyD** encapsulated square planar palladium complexes via the silver route.

Alternative routes reported for the preparation of NHC-palladium complexes involve *in situ* deprotonation of an azolium salt in the presence of a palladium precursor.[26] Convenient one-step procedures have been described with K_2CO_3 as the base and 3-chloro-pyridine or pyridine as the solvent.[27] By using these conditions, (**β-ICyD**)$PdCl_2$(pyridine) and (**γ-ICyD**)$PdCl_2$(pyridine) were successfuly isolated in 68% and 88% yield, respectively, from the corresponding azolium salts (**β-ICyD**)HCl and (**γ-ICyD**)HCl. However, the same reaction conditions applied to **(α-ICyD)**HCl, led to the formation of an unexpected complex, which appeared to be the outwardly oriented **α-ICyD**-palladium complex, named **(α-out-ICyD)**$PdCl_2$(pyridine), which was isolated in 62% yield without trace of the introverted square planar complex. Similarly, treatment of **(α-ICyD)**HCl with K_2CO_3 and 0.5 equivalents of [Pd(η^3-allyl)Cl_2]$_2$ led to the exclusive formation of the **(α-out-ICyD)**PdCl(η^3-allyl) complex in 62% yield. (Scheme 4)



Scheme 4. One-step formation of encapsulated **(ICyD)**Pd complexes from the imidazolium salts.

The extraverted or introverted conformations of the Pd complexes were determined by NMR spectroscopy. First, comparison of the ^{1}H NMR spectra of the three **(ICyD)**$PdCl_2$(pyr) complexes showed an unusual deshielding of the protons borne by the NHC ring (called H^{Im}) for the α**-out-ICyD** complex compared to the β- and γ-**ICyD** Pd complexes (Figure 2). Another anomaly observed in the spectrum of the α**-out-ICyD** Pd complex was the relative shielding of H^5s. In fact, the deshielding of the H^5s, especially those situated on the sugars bearing the NHC, has been diagnostic for the encapsulation of a metal inside the CD cavity in all our work on ICyDs so far.[14,15] These two features were consistent with both a different conformation and positioning of the metal related to the cavity for the α-CD-derived **ICyD** Pd complex.

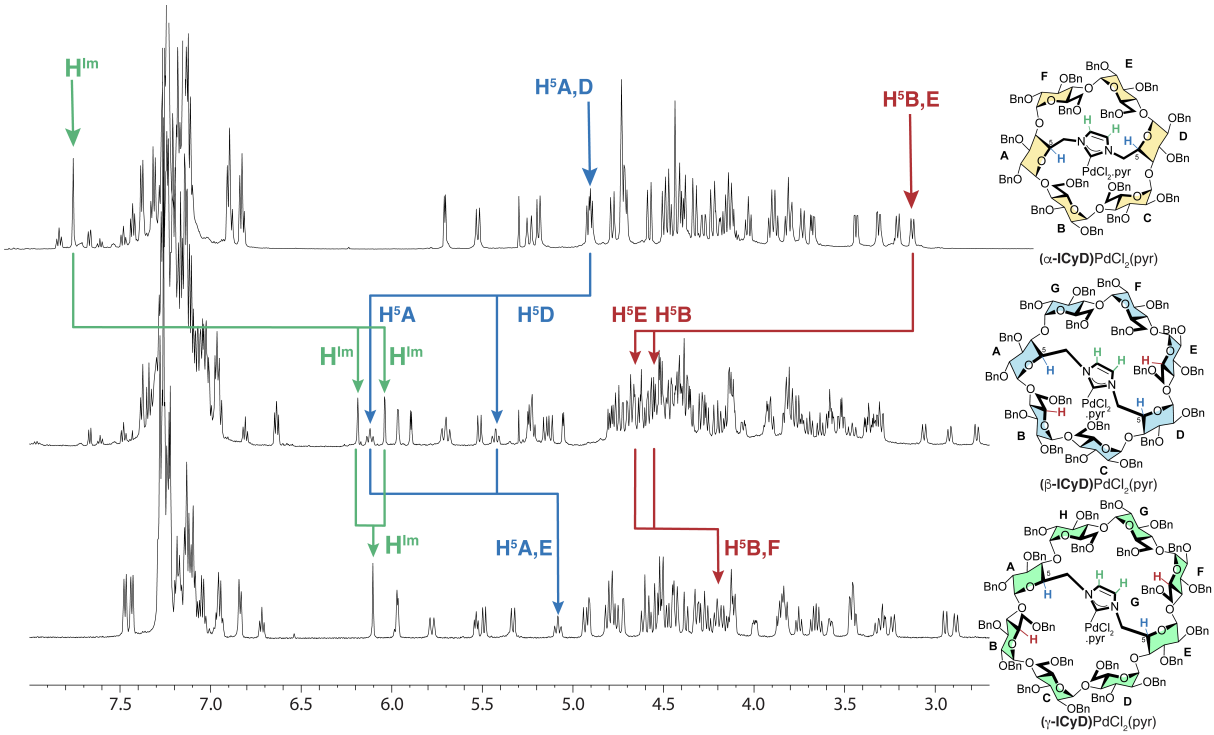


Figure 2. Comparison of ^{1}H NMR spectra of (α-**out-ICyD**)$PdCl_2$(pyr) (top), (β-**ICyD**)$PdCl_2$(pyr) (middle) and (γ-**ICyD**)$PdCl_2$(pyr) (bottom).

NOESY experiments performed on the α-CD-derived **ICyD** Pd complex were particularly informative, as cross-correlations between H^{Im} and introverted protons $H^{5(A,D)}$ and $H^{3(C,F)}$ were observed. (Figure 3A) This observation clearly confirmed that the NHC ligand was reversed in this case inducing coordination of the Pd atom outside the cavity, whereas in both β-and γ-CDs, the metal is still encapsulated, their H^{Im} correlating with H^{6} protons from the upper rim. (Figures 3B, 3C)

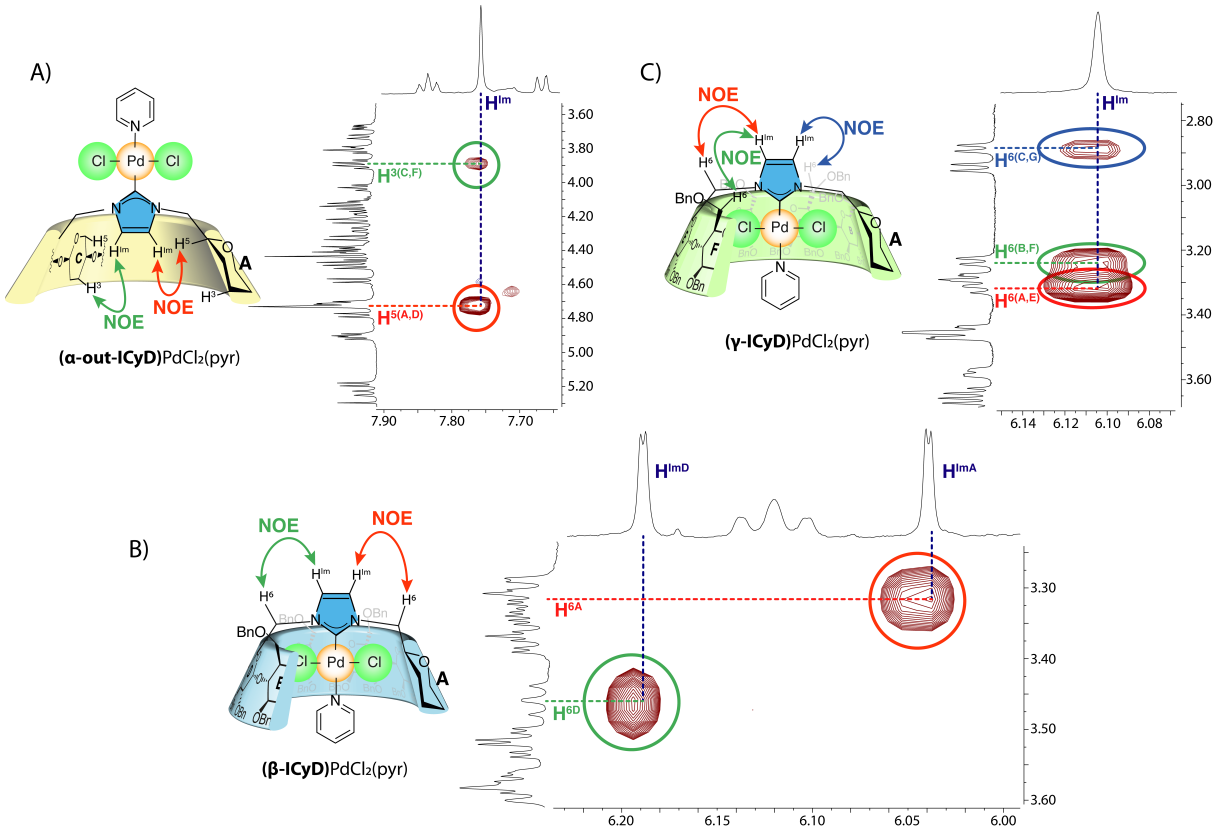
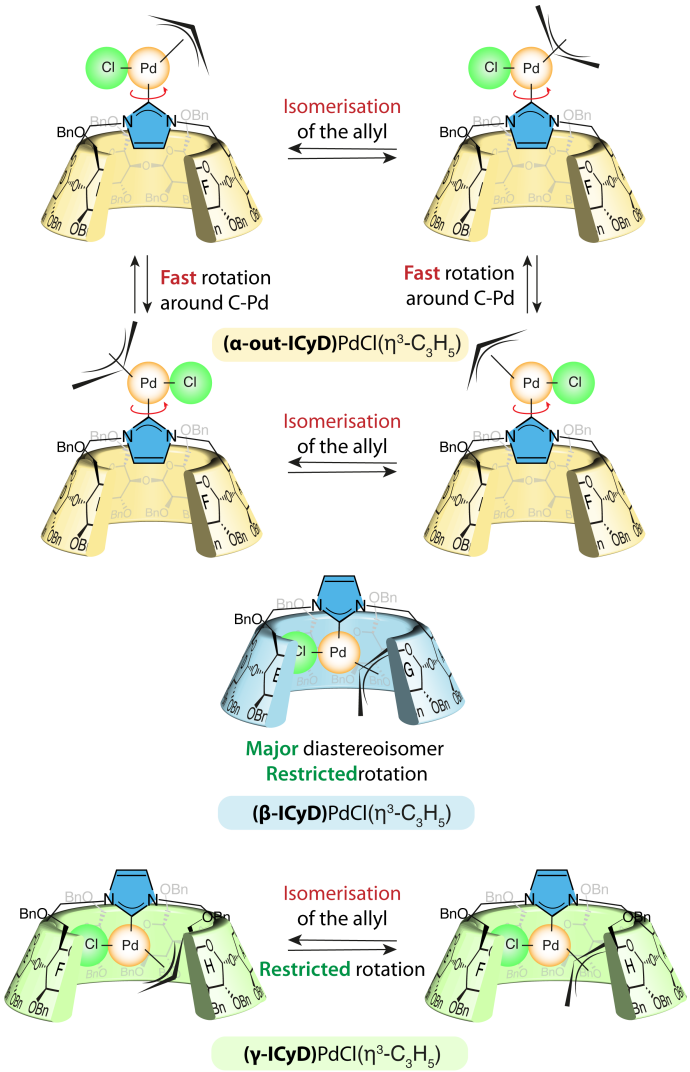


Figure 3. Cross-correlations observed by NOESY experiments for the introverted and extraverted conformations of (**ICyD**)Pd^{II} complexes.

We also carefully studied (**ICyD**)PdCl(η^3-allyl) complexes and demonstrated in the same manner that the Pd atom was inside the cavity of both β- and γ-CDs whereas it is outside in the case of α-CD. In (NHC)Pd(allyl)Cl complexes, due to the non-symmetrical coordination of the η^3-allyl ligand, the palladium atom is a stereogenic center and coordination to a chiral NHC leads to a possible mixture of diastereoisomers.[25,28] Note that α-**ICyD** and γ-**ICyD** are both C_2-symmetric ligands whereas β-**ICyD** is C_1-symmetric. Complexation of the PdCl(allyl) outside the cavity of **α-ICyD** and inside the cavity of **γ-ICyD** gave two diastereoisomers in a very similar ratio (*dr* 1:1 and 6:4, respectively). In contrast, the complexation with β-**ICyD** gave one predominant diastereoisomer (*dr* = 97:3) for (**β-ICyD**)PdCl(η^3-allyl), clearly showing the influence of the topography of the cavity on the structure of the complex. In addition, **(α-out-ICyD)**PdCl(η^3-allyl) appears as a mixture of two C_2-symmetric diastereomers, while its **γ-**CD counterpart displays two sets of signals corresponding to two C_1-symmetric molecules (indicating a loss of C_2 symmetry). This result suggests that the kinetics associated with the conformations of (γ-**ICyD**)PdCl(η^3-allyl) are different from those of (**α-**out-**ICyD**)PdCl(η^3-allyl). NOESY experiments performed on the **γ-**CD-derived complex showed exchange signals between H_{syn} and H_{anti} of the allyl unit characteristic of an isomerization of the allyl moiety. These observations suggest that the rotation around the NHC–Pd bond is restricted in (γ-**ICyD**)PdCl(η^3-allyl). As a consequence, (γ-**ICyD**)PdCl(η^3-allyl) appears as a mixture of two asymmetrical diastereomers, in which each of the eight glycosyl subunits are differenciated. For (**α-out-ICyD**)PdCl(η^3-allyl), for which the PdCl(η^3-allyl) unit is outside of the cavity, a rapid rotation around the Pd–NHC bond[29] in the NMR time scale may account for the observation of a C_2 symmetry. Finally, with β-**ICyD** as ligand, both a restriction in the rotation around the NHC–Pd bond and a high stereoselectivity in favor of one configuration of the

PdCl(η^3-allyl) unit led to the observation of one highly predominant diastereoisomer. These three very distinct behaviors illustrate once again, but in a different way, the influence of the shape of the cavity on the encapsulated complexes. (Scheme 5)



Scheme 5. Difference in the dynamics of isomerization of the allyl and rotation around the C-Pd bond imposed by the three cavities.

As mentioned above, (β-**ICyD**)Pd(η^3-allyl)Cl appears as a major isomer with restricted rotation around the NHC–Pd bond along with a preferred configuration of the PdCl(η^3-allyl) unit. We therefore embarked in the determination of its structure by NMR. In (**ICyD**)MX complexes, the chemical shifts of introverted H^5 and H^3 are sensitive to the proximity of the encapsulated metal and halogen. For (β-**ICyD**)Pd(η^3-allyl)Cl, careful observation of the chemical shifts of the H^5 was determinant to establish the position of the chloride ligand inside the cavity. As expected and characteristic of all introverted **ICyD**–metal complexes, a downfield shift of both H^{5A} and H^{5D} was observed, which was attributed to C-H···Pd interactions. However, comparison of the chemical shifts of the other H^5 showed unusual downfield shifts for those of sugar units E and F (deshielded by almost by 1 ppm compared to H^5 of units C and G). In contrast, no deshielding was observed for H^5 protons belonging to sugar units B and C. We therefore propose that in (β-**ICyD**)Pd(η^3-allyl)Cl the Cl atom is close to H^{5E} and H^{5F} and thus, encapsulated in the largest loop of the macrocycle (AGFED

cycle), inducing a restricted rotation around the NHC–Pd bond. As a consequence, provided that the square planar geometry around the palladium atom is preserved, we assumed that the allyl unit was placed in the smallest loop of the macrocycle (ABCD cycle). From this result, the configuration of the allyl moiety could be determined by 2D-NOESY showing a cross-correlation peak between the $H_{anti}(C_{cis})$ of the allyl moiety and the H^5 of the sugar unit A that bears the NHC-bridge (see SI and figure 4). A plausible structure for (β-**ICyD**)Pd(η^3-allyl)Cl based on these observations is presented in figure 4.

Table 1. Chemical shifts of H^3 and H^5 of (β-ICyD)PdCl(η^3-allyl).

Complex	H	Cycle A	Cycle B	Cycle C	Cycle D	Cycle E	Cycle F	Cycle G
(β-ICyD)$PdCl_2$(η^3-allyl)	H^5	5.13	3.54	4.01	4.79	4.82	4.91	4.09
	H^3	3.81	4.08	4.13	4.13	4.08	4.50	4.75

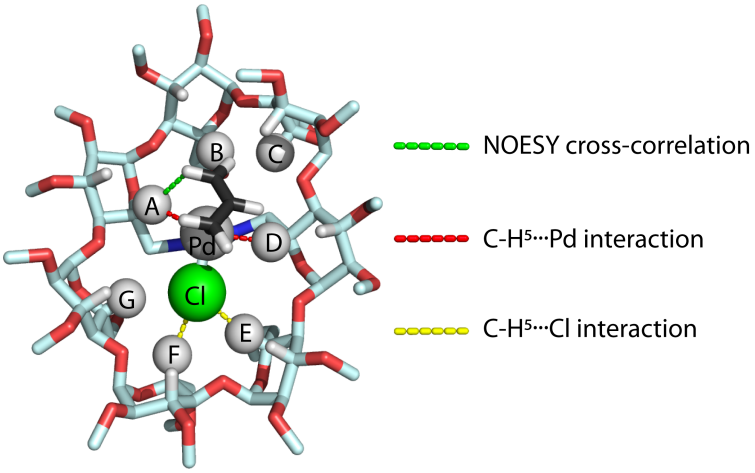
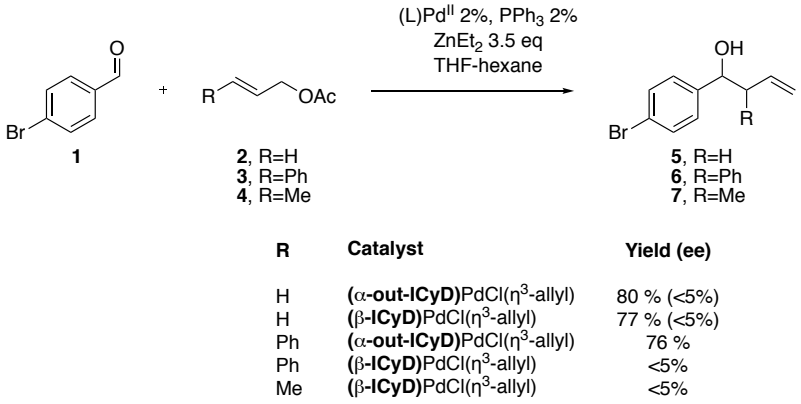


Figure 4. Proposed structure of **(β-ICyD)**PdCl(η^3-allyl) based on NMR.

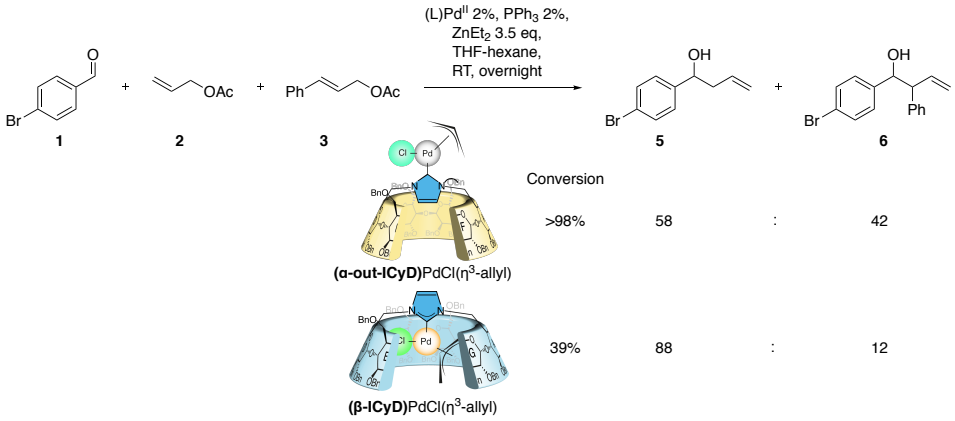
We next turned our attention to the Pd^{II}-catalyzed nucleophilic allylation of aromatic aldehydes.[30] The reaction was described with NHC ligands,[31] with very few examples of enantioselective versions with chiral NHCs.[32,33] Both complexes **(α-out-ICyD)**PdCl(η^3-allyl) and **(β-ICyD)**PdCl(η^3-allyl) were found to catalyze the reaction of 4-bromobenzaldehyde **1** with allyl acetate **2** to give the expected product in 80% and 77% yield, respectively, but with almost no enantioselectivity. The reaction of cinnamyl acetate **3** was more contrasted as **(α-out-ICyD)**PdCl(η^3-allyl) gave compound **6** in 76% yield, while, the more sterically demanding **(β-ICyD)**PdCl(η^3-allyl) gave no conversion of this substrate. Similarly, crotyl acetate **4** did not react in the presence of **β-ICyD** Pd complex, therefore confirming that this β-CD-derived ligand is highly sensitive to the size of the substrate in this reaction. (Scheme 6)



R	Catalyst	Yield (ee)
H	**(α-out-ICyD)**PdCl(η^3-allyl)	80 % (<5%)
H	**(β-ICyD)**PdCl(η^3-allyl)	77 % (<5%)
Ph	**(α-out-ICyD)**PdCl(η^3-allyl)	76 %
Ph	**(β-ICyD)**PdCl(η^3-allyl)	<5%
Me	**(β-ICyD)**PdCl(η^3-allyl)	<5%

Scheme 6. Pd^{II}-catalyzed nucleophilic allylation of aromatic aldehydes

Substrate discriminating reactions are a topic of interest in bio-inspired reactivity.[34] We therefore studied the behavior of both ***α*-out-ICyD** and ***β*-ICyD** in a reaction with a 1:1 mixture of allyl acetate **2** and cinnamyl acetate **3** (0.6 equivalents each). Under these conditions, the reversed complex ***α*-out-ICyD** gave a high conversion (>98%) and a close proportion (58:42) of both products **5** and **6**, although a slight preference for allyl acetate as substrate is observed. In contrast, **(*β*-ICyD)**PdCl(*η*^{3}-allyl), in the same reaction conditions, afforded a 88:12 mixture of **5** and **6** and a rather low conversion (39%). This latter result showed how the wrapping of the metal center in the β-CD cavity generates a steric hindrance that can be used to develop a substrate selective reaction by favoring the reaction with the smallest substrate (allyl acetate). In contrast and as expected, the outer coordination of the Pd reactive center towards the primary rim of the CD when using ***α*-out-ICyD** ligand, has almost no effect on the properties of the metal to discriminate different substrates according to their size. (Scheme 7)



Scheme 7. Substrate selection by ***α*-out-ICyD** and ***β*-ICyD**.

Conclusion

In conclusion, we have shown that the formation of encapsulated square planar Au^{III} and Pd^{II} complexes with **ICyD** ligands was only possible in the largest β- and γ-CD cavities. The size of the CD cavity was also found to have a significant effect on the possibility to oxidize Au^{I} into Au^{III}. For instance, **(α-ICyD)**AuCl could not be oxidized, whereas β- and **γ-ICyDs** Au^{I} complexes could. However, only Cl_2 and Br_2 reacted with the β-CD complex, when I_2 only reacted with the larger γ-CD-based complex. So, the size of the cavity clearly controls the reactivity of the complex towards this

oxidation reaction. For the formation of Pd^{II} complexes, in the case of **α-ICyD**, an unexpected reversal of the NHC ligand was observed, when both β- and γ-**ICyDs** kept the metal inside their cavities. These extraverted or introverted conformations of the Pd complexes were carefully studied by NMR which revealed their different behaviors depending on the cavity. For instance, for the PdCl(η^3-allyl) complex, the reversed α-CD complex allows free rotation around NHC-Pd bond and fast isomerization of the allyl. β-ICyD encapsulates this complex and the rotation is restricted by the cavity, which also favors one stereoisomer of the allyl. Finally, γ-ICyD also restricts the rotation of the same complex but still allows isomerization of the allyl of the complex in the cavity. Finally, in a Pd^{II}-catalyzed nucleophilic allylation of aldehydes, the β-CD-derived ligand was able to discriminate different substrates from a mixture according to their size, leading to a significantly favored reaction with the smaller substrate. Once again the topographical variety in the ICyD family demonstrates a cavity-controled variation in behaviors of included square planar complexes complexes.

Experimental Section

(β-ICyD)$AuCl_3$

Into a solution of **(β-ICyD)**AuCl (20mg, 6,4 of µmol) in CH_2Cl_2 (2,5 mL) at -78°C, Cl_2 is slowly bubbled until the reaction mixture becomes slightly yellow. The reaction is monitored by TLC (CyH:EtOAc 3:1) until completion. Solid K_2CO_3 is then added, Ar bubbled and the reaction mixture is slowly warmed to -30°C. Ar is bubbled until loss of yellow coloration. K_2CO_3 was filtered over a pad of cotton wool and CH_2Cl_2 is evaporated in vacuo until dryness without heating to give which was characterized without any further purification. ^{1}H-NMR: (600 MHz, Acetone-d_6) δ 7.55 - 6.93 (m, 96H, 94xH-Ar, 2xN-CH=C), 6.81 (t, J = 7.5 Hz, 2H, H-Ar), 5.91 (d, $^3J_{1,2}$ = 3.8 Hz, 1H, H-1G), 5.82 (d, $^3J_{1,2}$ = 3.5 Hz, 1H, H1-C), 5.70 (d, J = 11.4 Hz, 1H, PhCHH), 5.64 (d, $^2J_{Ph\text{-}CHH}$ = 10.8 Hz, 1H, PhCHH), 5.54 (dd, J = 13.4, 2.6 Hz, 1H, H-6D), 5.37 - 5.29 (m, $^2J_{6a,6b}$ = 13.2 Hz, $^3J_{6,5}$ = 2.6 Hz, 2H, H-6A,CHPh), 5.28 - 5.22 (m, 2H, 2 x PhCHH), 5.20 - 5.15 (m, 2H, PhCHH, H-1D), 5.05 (d, $^2J_{Ph\text{-}CHH}$ = 11.1 Hz, 1H, PhCHH), 5.02 - 4.66 (m, 16H, H-5A, H-5D, H-3C, H-3E, H-1A, H-1B, H-1E, H-1F, 8 x PhCHH), 4.65 - 4.07 (m, 33H, H-5B, H-5E, H-5F, H-3B, H-3D, H-3F, H-3G, H-4C, H-6G, H-6D, 23 x CH_2Ph) 4.05 - 3.54 (m, 19H, H-3A, H-4A, H-4B, H-4D, H-4E, H-4F, H-4G, H-5C, H-5G, H-6A, 2 x H-6C, H-6D, 2xH-6F, H-6G, H-2D, H-2G, PhCHH), 3,51 (d, $^3J_{2,3}$ = 10.8 Hz, $^3J_{2,1}$ = 3.7 Hz, 1H, H-2C), 3,44 (d, $^3J_{2,1}$ = 9.8 Hz, $^3J_{2,1}$ = 2.9 Hz, 1H, H-2A), 3,37 - 3.30 (m, 2H, H2-B, H2-F), 3.30 - 3.12 (m, $^3J_{2,1}$ = 9.7, $^3J_{2,1}$ = 2.7 Hz, 4H, H-2E, 2 x H-6B, H-6E). ^{13}C-NMR(151 MHz, Acetone-d_6) δ 143.0 (C=Au), 141.8, 141.5, 141.2, 140.9, 140.8, 140.2, 140.1, 140.0, 140.0, 139.9, 139.9, 139.8, 139.7, 139.6, 139.1, (C_{ipso}), 129.3-, 127.4 (CH Ar, 2xN-CH-CH-N), 101.3 (C-1E), 99.8 (C-1F), 99.1 (C-1D), 98.6 (C-1B), 98.5 (C-1A), 98.4 (C-1C), 97.8 (C-1G), 84.0 (C-4F), 83.0 (C-4G), 2x82.7 (C-4C, C-4E), 82.6 (C-3A), 82.5 (C-3D), 2x81.70 (C-2D,C-4B), 81.40 (C-2A), 81.2 (C-3F), 80.9 (C-2F), 80.5 (C-2B), 80.3 (C-3E), 80.0 (C-3G), 79.8 (C-2E), 78.96(C-3C), 78.3 (C-2C), 78.3(C-2G), 77.0-75.2 (CH_2Ph), 74.8 (C-5GorC-5C), 74.5 (C-4D), 74.1 (C-5G or C-5C), 74.3-72.6 (CH_2Ph), 73.7 (C-4A), 73.2 (C-5F), 72.9 (C-5A), 72.85 (C-5B), 72.1 (C-5E), 71.1 (C-6C), 70,9 (C-6F), 70.8 (C-5D) 70,5 (C-6G), 69.8 (C-6E), 69.7 (C-6B) 54.8 (C-6D), 53.8 (C-6A). HRMS (ESI, injection in MeCN): calculated for $C_{178}H_{184}AuCl_3N_2O_{33}Na$ $[M+Na]^+$ found 3205.1386 calculated 3205.1416 err=-0.9 ppm. Rf=0.43 (CyH:AcOEt 3:1)

(γ-ICyD)$AuCl_3$

(γ-ICyD) AgCl (55 mg, 18 µmol) and gold(I) chloride (35.5 mg, 90 µmol, 8eq) were weighed in a sealed tube and purged with Ar. Then, dry MeCN (2mL) was added. The reaction mixture was stirred at room temperature for 18h. The reaction mixture was evaporated under reduced pressure and charged directly on a silica gel column, eluted with a gradient CyH:EtOAc 5:1 to 4:1. After evaporation of the sovents **(γ-ICyD)**$AuCl_3$ complex (22mg, 38%)was obtained as a white foam. ^{1}H-NMR (chloroform-d, 600MHz): 7.45 - 7.00 (m, C-H_{Arom}), 6.81 (t, 2H, 2xC-H_{para}), 6.03 (s, 2H, 2 x N-CH=CH-N), 5.69, (d, $^2J_{1,2}$ = 4.1 Hz, 2H, 2 x H-1D,H), 5.43 (d, $^2J_{CHHPh}$ = 11.4 Hz, 2H, 2 x PhCHH), 5.29 (d, $^2J_{CHHPh}$, 4H, 4 x PhCHH), 5.16 (dd, $^2J_{6A,6B}$ = 14.2 Hz, $^3J_{6a,5}$ = 2.4 Hz, 2H, 2 x H-6A,E), 5.12 (d, $^2J_{CHHPh}$ = 11.7 Hz, 2H, 2 x PhCHH), 4.84 - 4.78 (m, 8H, 6 x PhCHH, 2 x H-1C,F), 4.75 - 4.69 (m, 6H, 2 x PhCHH, 2 x H-1A,E, 2 x H-1B,F), 4.61 (d, $^2J_{CHHPh}$ = 11.5 Hz, 2H, 2 x PhCHH), 4.67 - 4.22 (m, 32H, 2 x H-5A,E, 2 x H-3D,H, 28 x PhCHH), 4.16 (dd, 2H, $^2J_{6a,6b}$ = 11.3Hz, $^3J_{6a,5}$=4.5Hz, 2 x H-6C,G, 2 x H-6D,H), 4.04 (m, 2H, 2 x H-3C,G) 3.97 - 3.82 (m, 12H, 2 x H-3A,E, 2 x H-6C,G, 2 x H-3B,F, 2 x H-5C,G, 2 x H-6D,H, 2 x H-4D,H), 3.77 - 3.75 (m,4H, 2 x H-4B,F, 2 x H-5B,F),

3.69 (dd, $^{2}J_{6a\text{-}6b}$ = 10.55 Hz, $^{3}J_{6a,5}$ = 5.4 Hz, 2H, 2 x H-6C,G), 3.59 (d, 2H, $^{3}J_{4,5}$ = $^{3}J_{4,3}$ = 9.2Hz, 2 x H-4C,G), 3.56 - 3.48 (m, 6H, 2 x H-2D,H, 2 x H-4A,E, 2 x H-5D,H), 3.39 - 3.34 (m, 4H, 2 x H-2C,G, 2 x H-2B,F), 3.32 - 3.30 (m, 4H, 2 x H-2A,E, 2 x H-6A,/E) 3.05 (dd, 2H , $^{2}J_{6a\text{-}6b}$ = 10.8 Hz, 2 x H-6B,F), 2.89 (dd, 2H , $^{2}J_{6a\text{-}6b}$ = 11.0 Hz, 2 x H-6B,F). ^{1}H NMR (600 MHz, Acetone – d_6) δ 7.50 – 7.08 (m, 137H, CH_{Ar}), 7.09 – 6.98 (m, 7H, CH_{Ar}, 2 x N-CH=CH-N), 6.81 (t, *J* = 7.4 Hz, 2H, CH_{para}), 5.85 (d, *J* = 3.8 Hz, 2H, H-1D/H), 5.62 (d, *J* = 11.2 Hz, 2H, 2 x CHHPh), 5.48 – 5.39 (m, 4H, 4 x CHHPh), 5.32 – 5.24 (m, 4H, 2 x CHHPh, H-6A/E), 5.17 (d, *J* = 11.5 Hz, 2H, 2 x CHHPh), 5.04 (d, *J* = 3.1 Hz, 2H, H-1A/E), 4.93 (2 x d, *J* = 3.4 Hz, 2H, H-1C/G, H-1B/F), 4.84 – 4.70 (m, 13H, 13 x CHHPh), 4.61 – 4.24 (m, 45H, H-3D/H, H-6D/H, H-5A/E, CHHPh), 4.14 (t, *J* = 9.3 Hz, 2H, H-C/G), 4.10 – 3.99 (m, 6H, H-4D/H, H-3A/E, H-5C/G), 3.99 – 3.56 (m, 27H, H-5D/H, H-5B/F, H-3B/F, H-4B/F, H-4C/G, H-4A/E, H-6D/H, H-6A/E, H-6C/G, H-6C/G, CHHPh), 3.55 – 3.41 (m, 4H, H-2D/H, H-2A/E), 3.40 – 3.32 (m, 6H, H-2B/F, H-2C/G, H-6B/F), 3.20 (d, *J* = 11.2 Hz, 2H, H-6B/F). ^{13}C-NMR: (151 MHz, Chloroform-d) δ = 145.4 (C=Au^{III}), 140.6 - 138.2 (C_{ipso}), 128.7 - 124.9 (CH_{Arom}), 124.5 (C_{Imid}), 99.4 (C-1B/F), 98.9 (C-1C/G), 98.3 (C-1A/E), 94.7 (C-1D/H), 82.5 (C-4C/G), 82.0 (C-4D/H), 80.8 (C-3A/E, C-3C/G), 80.3 (C-2A/E, C-4B/F), 80.0 (C-3B/F), 79.6 (C-3D/H), 79.0 (C-2B/F or C-2C/G), 78.7 (C-2B/F or C-2C/G), 77.5 (C-2D/H), 77.0 (CH_2Ph), 76.9 (CH_2Ph), 76.7(CH_2Ph), 76.0 (2 x CH_2Ph), 74.0 (CH_2Ph), 73.7 (CH_2Ph), 73.4 (CH_2Ph), 73.0 (CH_2Ph), 73.0 (H-5D/H), 72.6 (CH_2Ph), 72.3 (CH_2Ph), 72.2 (CH_2Ph), 72.1 (C-5C/G), 71.2 (C-4A/E), 71.0 (C-5B/F), 70.9 (C-5A/E), 70.7 (C-6C/G), 70.0 (C-6D/H), 68.7 (C-6B/F), 53.1 (C-6A/E). ^{13}C NMR (151 MHz, Acetone- d_6) δ 143.8 (C=Au) 142.0, 141.1, 141.0, 140.2, 140.1, 139.9, 139.7, 139.1, (Cipso) 129.4, 129.3, 129.2, 129.2, 129.2, 129.0, 129.0, 129.0, 128.9, 128.9, 128.8, 128.8, 128.7, 128.6, 128.6, 128.5, 128.3, 128.3, 128.2 (CHAr), 128.2 (CImid), 128.0, 127.8, 127.6, 127.6, 127.3, 126.9 (CHAr), 99.6 (C-1B/F), 99.4 (C-1C/G), 98.7 (C-1A/E), 95.0 (C-1D/H), 83.0 (C-4C/G), 82.7 (C-4D/H), 82.0 (C-3C/G) 81.4 (C-3A/E), 81.1 (C-3B/F, C-4B/F), 81.0 (C-2A/E), 80.3 (C-2C/G), 80.2 (C-2B/F), 80.1(C-3D/H), 79.2(C-2D/H), 77.7 (CH_2Ph), 77.4 (CH_2Ph), 76.7 (CH_2Ph), 74.4 (CH_2Ph), 74.0 (CH_2Ph), 74.0 (CH_2Ph), 73.8 (C-5D/H), 73.2 (C-5B/F), 73.1 (C-5C/G), 72.8 (CH_2Ph), 72.4 (CH_2Ph), 72.2 (CH_2Ph), 71.9 (C-5A/E), 71.8 (C-4A/E), 71.2 (C-6C/G), 70.6 (C-6D/H), 69.7 (C-6B/F), 54.2 (C-6A/E). HRMS (ESI): calculated for $C_{205}H_{212}AuCl_3N_2O_{38}NaK$ $[M+Na+K]^{2+}$ 1836.6486 found 1836.6430 err 3.1 ppm. Rf: 0.37 (CyH : AcOEt 3 : 1)

(γ-ICyD)AuClBr$_2$

A solution of Br_2 (0.25 µL in 2 mL of CH_2Cl_2, 4.77 µmol) was added into a solution of **(γ-ICyD)**AuCl complex (15mg, 4.34 µmol, 1 eq) in 1 mL of CH_2Cl_2 previously cooled at -30°C. The reaction was stirred for 30 minutes and followed by TLC and Mass spectrometry. Upon completion, the reaction media was concentrated in vacuum at room temperature and the NMR analysis of **(γ-ICyD)**$AuClBr_2$ was done without further purification. ^{1}H-NMR: (400MHz, acetone-d_6): 7.55- 7.10 (m, 100H, H-Ar), 7.05-7.00 (m, 6H, 2 x HAr, 2 x H-Imid), 6.75 (t, ^{3}J = 7.4 Hz, 2H, 2 x H_{Ar}), 5.86 (d, $^{3}J_{1,2}$ = 3.7 Hz, 2H, 2 x H-1D,H), 5.70 (d, $^{2}J_{PhCHH}$ = 11.5Hz, 2H, PhCHH), 5.44 (d, $^{2}J_{CHHPh}$ = 10.60 Hz, 2H, PhCHH), 5.25 (dd, 2H, $^{2}J_{6a,6b}$ = 13.9, $^{3}J_{6,5}$ = 2.1 Hz, 2 x H-6A,E), 5.13 (d, 2H, $^{2}J_{CHHPh}$ = 11.6 Hz, PhCHH), 5.07 (d, $^{3}J_{1,2}$ = 3.0 Hz, 2H, 2 x H-1A,E), 4.93 (2 x d, 2 x $^{3}J_{1,2}$ = 3.4 Hz, 2H, 2 x H-1B,D, 2 x H-1C,D), 4.83 (d, $^{2}J_{CHHPh}$ =10.3 Hz, 2H, 2 x PhCHH), 4.87 - 4.66 (m, 8H, 8 x PhCHH), 4.65 - 4.35 (m, 24H, 2 x H-5A,E, 2 x H-3C,F, 20 x PhCHH), 4.33 - 4.22 (m, 4H, 2 x H-6D,H, 2 x PhCHH), 4.20 - 3.81 (m, 20H, H-6A,E, 2 x H-6C,G, 2 x H-4D,H, 2 x H-3C,G, 2 x H-3B,F, 2 x H-4B,F, 2 x H-6D,H, 2 x H-5B,F, 2 x H-5C,F), 3.76 - 3.60 (m, 6H, 2 x H-5D,H, 2 x H-4C,G, 2 x H-4A,E), 3.52 (dd, $^{3}J_{2,3}$ = 9.9 Hz, $^{3}J_{2,3}$ = 3.7 Hz, 2H, 2 x H-2D,H), 3.49 - 3.41 (m, 4H, 2 x H-6B,F, 2 x H-2D,H), 3.40 - 3.30 (2 x dd, $^{3}J_{2,3}$ = 9.5, $^{3}J_{2,1}$ = 3.3 Hz, $^{3}J_{2,3}$ =9.9, $^{3}J_{2,1}$ = 3.3 Hz, 4H, 2 x H-2B/F, 2 x H-2C/G), 3.25 (2H, bd, 2 x H-6B,F). ^{13}C-NMR (100MHz, acetone-d_6): 142.3 (C=Au), 140.4-139.3 (C_{ipso}), 129.7-127.4 (C_{Ar}), 127.1 (N-CH=CH-N), 100.1 (C-1B,F), 99.8(C-1C,G), 98.5 (C-1A,E), 95.1 (C-1D,H), 83.2 (C-4C,G), 82.9 (C-3B,F), 82.3 (C-3C,G), 81.7 (C-3A,E), 81.5 (C-2A,E), 81.2 (C-4D,H), 80.9 (C-4B,F), 80.3 (C-2B,F, C-2C,G), 80.2 (C-3D,H), 79.4 (C-2D,H), 78.0, 77.6, 76.9, 74.4, 74.18, 74.1 (6 x CH_2Ph), 73.8 (C-5D,H), 74.5 (CH_2Ph), 73.4 (C-5C,G), 73.3, 72.9 (2 x CH_2Ph), 72.4 (C-5B,F), 72.2 (CH_2Ph), 71.9 (C-4A,E), 71.3 (C-5A,E), 71.2 (C-6C,G), 70.8 (C-6D,H), 69.9 (C-6B,F), 50.1 (C-6A,E). HRMS (ESI): calculated for: $C_{205}H_{212}AuBr_2ClN_2O_{38}Na$ $[M+Na]^{+}$, 3723.2365 found 3723.2703 err 9.07 ppm. Rf = 0.41 (CyH:AcOEt, 3 : 1)

(γ-ICyD)AuClI$_2$

A solution of I_2 (1.07 mg in 2 mL of CH_2Cl_2, 4.77 µmol) was added into a solution of **(γ-ICyD)**AuCl complex (15mg, 4.34 µmol, 1 eq) in 1 mL of CH_2Cl_2 previously cooled at -30°C. The reaction was stirred for 30 minutes and followed by Mass spectrometry. Upon completion, the reaction media was concentrated in vacuum at room temperature and the NMR analysis of **(γ-ICyD)**$AuClI_2$ was done without further purification. ^{1}H NMR (600 MHz, Acetone-d_6) δ = 7.50 – 7.01 (m, 108H, H_{Ar}), 7.00 (s, 2H, N-CH=CH-N) 6.80 (t, $^{3}J_{p,m}$ = 7.4 Hz, 2H, H_{paraBn}), 5.85 (d, $^{3}J_{H1\text{-}H2}$ = 3.8 Hz, 2H, H-1D,H), 5.62 (d, $^{3}J_{PhCHH}$ = 11.3 Hz, 2H), 5.43 (2 x d, $_{PhCHH}$ = 15.8 Hz, 10.9 Hz, 4H, PhCHH), 5.17 — 5.07 (m, 6H, 2 x PhCHH, 2 x H-1A,E, 2 x H-6A,E), 4.93 (2 x d, $^{3}J_{H1\text{-}H2}$ = 3.4 Hz, 4H, 2 x H-1B,F, 2 x H-1C,G),

4.82 – 4.73 (m, 8H, 2 x H-5A,E, 6 x PhCHH), 4.58 – 4.39 (m, 37H, 2 x H-5B,F, 2 x H-3D,H, PhCHH), 4.30 (dd, $^{2}J_{H6a-H6b}$ = 11.3 Hz $^{3}J_{H6-H5}$ = 3.11 Hz, H-6D,H) , 4.21 — 4.11 (m, 6H, 2 x H-3C,G, 2 x H-5B,F, 2 x PhCHH), 4.18 — 4.10 (m, 4H, 2 x PhCHH, 2 x H-5C,G), 4.09 – 3.59 (m, 16H, 6 x H-3A,B,C,E,F,G, 8 x H-4A,B,C,D,E,F,G,H, 2 x H-5 D,H, 10 x H-6A,B,C,D,E,F,G,H), 3.54 (dd, $^{2}J_{H2-H3}$ = 10.0 Hz, $^{3}J_{H1-H2}$ = 3.6 Hz, 2H, H-6D,H), 3.46 (d, $^{3}J_{H2-H3}$ = 9.5 Hz, $^{3}J_{H1-H2}$ = 2.1Hz, 2H, H-2A,E), 3.37 (2 x dd, $^{3}J_{H2-H3}$ = 9.7, $^{3}J_{H1-H2}$ = 3.2Hz, 4H, 2 x H-2B,F, 2 x H-2C,G). ^{13}C NMR (151 MHz, Acetone) δ 142.0 — 138.9 (C_{ipso}), 131.3 (C=Au^{III}) 129.4 — 126.9 (CH_{Ar}), 119.1 (N-CH=CH-N), 100.5 (C-1B,F), 99.8 (C-1C,G), 98.1 (C-1A;E), 94.9(C-1D,H), 83.3 (C-4C,G), 82.8 (C-4D,H), 82.2 (C-3C,G), 81.8 (C-3A,E), 81.5 (C-2A,E), 80.9, 80.4 (C-3B,F, C-4B,F), 80.1 (C-3D,H), 80.0 (C-2B,F, C-2C,G), 79.5 — 73.9 (CHHPh), 73.5 (C-4A,E), 73.4(CHHPh), 73.2 (C-5C,G), 73.1 (CHHPh), 72.6(CHHPh), 72.4(C-5B,F), 71.7 (CHHPh), 71.6 (C-5D,H), 70.9 (C6-C,G), 70.5 (C-&D,H), 70.3 (C-5A;E), 69.6 (C-6B,F), 54.7 (C-6A,E). MS (ESI): calculated for $C_{205}H_{212}AuCl_2N_2O_{38}Na$ $[M+Na]^+$ 3818.2054 found 3817.8503

(α-out-ICyD)PdCl(η^3-allyl)

(α-ICyD)HCl (150 mg, 60 µmol), K_2CO_3 (120mg, 840 µmol) and $[PdCl_2(\eta^3\text{-allyl})]_2$ (11.1, 30 µmol) were purged under Ar and dissolved in CH_2Cl_2 (1 mL). The reaction mixture was stirred for 18 hours at room temperature. The solvent was evaporated and the product was filtrated on a silica gel column (CyH : AcOEt 4 : 1) affording **(α-out-ICyD)**PdCl(η^3-allyl) as a 1:1 mixture of diastereoisomers and a pale yellow foam (106 mg, 66%). ^{1}H NMR: (600 MHz, Chloroform-d) δ = 7.71 (2 x s, 4H, NCHHCN), 7.41 (m, 9H, H_{Ar}), 7.37 – 7.05 (m, 145H, H_{Ar}), 7.04 – 6.79 (m, 21H, H_{Ar}), 5.66 (2 x d, 2 x $^{3}J_{H1-H2}$ = 4.2 Hz, 4H, 4x C1), 5.52 (2 x d, $^{2}J_{PhCHH}$ = 11.0 Hz, 4H), 5.18 (2 x d, $^{2}J_{PhCHH}$ = 10.4 Hz, 4H), 5.03 – 4.82 (m, 10H, 8 x PhCHH, 2 x.H_{meso}), 4.81 – 4.68 (m, 14H), 4.64 (m, 11H), 4.57 – 4.18 (m, 45H), 4.16 – 4.02 (m, 17H), 4.02 – 3.90 (m, 4H), 3.86 (q, J=9.2, 7.1, 12H), 3.76 (td, J=10.7, 7.8, 6H), 3.72 – 3.62 (m, 7H), 3.58 – 3.37 (m, 8H), 3.29 (dd, J=10.0, 3.4, 4H), 3.20 (td, J=28.8, 26.7, 14.6, 6H), 3.13 – 2.96 (m, 9H), 2.19 (bd, J=12.0, 1H, $H_{cis\text{-}anti}$), 1.85 (bd, J=11.8 Hz, 1H, $H_{cis\text{-}anti}$). ^{13}C NMR (151 MHz, Chloroform-d) δ = 180.4 (C=Pd), 180.1 (C=Pd), 139.4 — 137.5 (C_{ipso}), 128.5 — 126.4 (CH_{Ar}), 120.1 (N-CH=CH-N), 115.0 (C_{meso}), 114.7 (C_{meso}), 100.3, 100.2, 99.5, 99.4, 96.5, 96.4 (C1), 82.5, 82.5, 82.4, 82.1, 80.9, 80.9, 80.3, 80.1, 79.9, 79.9, 78.5, 78.2, 78.1, 77.4, 77.2, 77.0, 76.9, 75.8, 74.4, 74.4, 74.1, 73.6, 73.6, 73.5, 73.4, 73.0, 72.6, 72.4, 72.3, 71.5, 69.8, 69.3, 69.2, 69.1, 63.0, 54.1, 48.2 (C_{cis}), 47.7 (C_{cis}). Rf=0.33 (CyH : AcOEt 3 : 1)

(α-out-ICyD)PdCl$_2$(pyr)

(α-ICyD)HCl (100 mg, 40 µmol), K_2CO_3 (87 mg, 560 µmol), and $PdCl_2(PhCN)_2$ (15.3 mg, 40 µmol) were weighted in a sealed tube and purged with Ar. Then pyridine (1 mL) was added. The reaction mixture was stirred for 18 hours at 80°C. After cooling down the mixture to room temperature, the solvent was evaporated and the product was filtrated on a silica gel column (CyH:AcOEt 4:1) affording **(α-out-ICyD)**$PdCl_2$(pyr) as a pale yellow foam (69 mg, 62 % yield). ^{1}H-NMR: (600 MHz, Chloroform-d): 9.01 (dd, $^{2}J_{ortho}$= 2H, HorthoPy), 7.83 (1H, HparaPy) 7.77 (s, 2H, HImid), 7.43 (m, 2H, HmetaPy), 7.40-7.05 (m, Harom), 6.92-6.88 (m, 6H, Hmeta/paraBn,2 x C-2C,F), 5.71 (d, $^{2}J_{H1,H2}$ = 4.1 Hz, 2H, 2x H-1C/F), 5.52 (d, $^{2}J_{PhCHH}$ = 11.3 Hz, 2H, PhCHH), 5.24 (dd, $^{2}J_{H6a-H6b}$ = 15.2 Hz, $^{3}J_{H6a-H5}$ = 1.7 Hz, 2H, H-6A,D), 5.19 (d, $^{2}J_{PhCHH}$=10.3, 2H, PhCHH) 4.91 (2xd, $^{2}J_{PhCHH}$=11.3Hz, 4H, 2xPHCHH), 4.78 (d, $^{2}J_{PhCHH}$ = 11.4 HZ, 2H, PhCHH) 4.75 — 4.69 (m, 10H, 4 x PhCHH, 2 x H-1A,D, 2 x H-1B,D, H-5A,D), 4.60 (d, 2H, $^{2}J_{PhCHH}$ = 11.9 Hz, PhCHH), 4.53 — 4.35 (m, 12H, 12 x PHCHH), 4.33 (d, $^{2}J_{PhCHH}$ = 11.9 Hz, 2H, 2 x PhCHH), 4.28 (dd, $^{2}J_{H6a,H6b}$ = 12.4 Hz, $^{3}J_{H6,H5}$ = 2.75 Hz, 2H, 2 x H-6B,E), 4.25 - 4.10 (m, 2 x PhCHH, 10H, 2 x H-3A,D, 2 x H-6A,D, 2 x H-4B,E, 2 x H-5C,F), 4.03 (t, $^{3}J_{H4,H5}$ = $^{3}J_{H4,H3}$ = 9.3 Hz, 2H, H-4C,F), 3.93 — 3.86 (m, 4H, 2xH3-B/D, 2xH3-C/F), 3.84 — 3.78 (m, 4H, 2 x H-4A,D, 2 x H-6B,D), 3.73 (dd, $^{2}J_{H6b-H6a}$ = 12.0 Hz $^{3}J_{H6b,H5}$ = 2.4 Hz, 2H, 2 x H-6C,F), 3.67 (d,, $^{3}J_{H2,H3}$ = 10.1 Hz, $^{3}J_{2,1}$ = 4.1 Hz, 2H, 2 x H-2C,F), 3.44 (d, $^{3}J_{H2,H3}$ = 9.2 Hz, $^{3}J_{2,1}$ = 3.4 Hz, 2H, 2 x H-2A,D), 3.32 (d, 2H, $^{3}J_{H2-H3}$ = 10.1 Hz, $^{3}J_{H2-H1}$ = 3.4 Hz, 2 x H-2B,E), 3.21 (bdd, 2H, 2 x H-5C,F), 3.13 (d, 2H, 2xH-5B,E). ^{13}C-NMR: (151MHz, Chloroform-d) 152.0 (C=Pd), 151.36 (2xCorthoPy), 139.4, 139.3, 139.2, 139.9, 138.6 (12xCipso), 138.3 (CparaPy), 137.8, 137.7 (4xCipso), 129.3-127.2 (CArom), 126.4 (Cortho-Bn3-A/D), 124.7 (2 x CmetaPy), 121.2 (2 x N-CH=CH-N), 100.2 (C-1C,F), 99.4 (C-1B,E), 96.2 (C-1A,D), 82.6 (C-3A,D), 81.8 (C-4C,F), 81.03 (C-3B,E), 80.99 (C-2A,D), 80.5 (C-3C,F), 79.86 (C-4B,E), 79.8 (C-4A,D), 78.6 (C-2B,E), 78.2 (C-2C,F), 77.0, 75.8, 74.3, 74.0,73.5, 73.4, 72.8, 72.55 (18xCHHPh), 72.4, (C-5C,F), 71.6 (C-5B,E), 70.3 (C-6B,E), 69.8 (C-6C,F), 68.9 (C-5A,D), 54.2 (C-6A,D). HRMS (ESI): calculated for $C_{156}H_{161}Cl_2N_3O_{28}PdNa_2$ $[M+2Na]^{2+}$, 1304.4751 found 1304.4702 err 3.8 ppm. Rf=0.35 (CyH:AcOEt 3:1)

(β-ICyD)PdCl(η^3 allyl)

(β-ICyD) AgCl (150mg, 49.7 μmol, 1eq) and allylpalladium(II) chloride dimer (9 mg, 49.7 μmol, 1eq) were weighed in a sealed tube and purged with Ar, then, dry DCM (1.5 mL)was added, and the reaction mixture was stirred at room temperature for 30 minutes. The reaction was followed by Mass Spectrometry and TLC, upon completion, silver salts were removed by filtration with a 0.2 μm PET filter and the solvent was evaporated in vacuo. After silica gel column filtration (CyH:AcOEt 3:1) **(β-ICyD)**PdCl(η^3 allyl) was obtained as a pale yellow foam (141 mg, 93%). ^{1}H-NMR: (600 MHz, acetone-$d_{6,}$) 7.49 - 6.94 (m, 94H, H Ar), 6.91 (d, $^2J_{NCH=CHN}$ = 1.7 Hz, 1H, H-ImD), 6.80 (d, $^2J_{NCH=CHN}$ = 1.7 Hz, 1H, HImA), 6.77 (m, 1H, HArp), 5.97 (d, $^2J_{1,2}$ = 3.8 Hz, 1H, H-1G), 5.94 (d, $^2J_{1,2}$ = 3.3 Hz, 1H, H-1C), 5.83 (d, $^2J_{CHHPh}$ = 11.7Hz, 1H, CHPh), 5.69 (heptuplet, ^{3}J = 6.2 Hz, 1H, Hallylmeso), 5,65 - 5.58 (m, 2H, H-6A, CHPh), 5.43 (d, $^2J_{1,2}$ = 11.2Hz, 1H, CHPh), 5.33 - 5.28 (m, 2H, 2xCH_2Ph), 5.13 (dt, $^2J_{CHHPh}$ = 10.7 Hz, $^3J_{6,5}$ = 1.8 Hz, 1H, H-5A), 5.08 (d, $^2J_{CHHPh}$ = 11.5Hz, 1H, CHPh), 5.03 (d, $^3J_{1,2}$ = 3.6Hz, 1H, H-1D), 5.01 - 4.96 (m, 3H, H-1F, 2xCHPh), 4.96 (d, $^3J_{1,2}$ = 3.6 Hz, 1H, H-1B), 4.94 - 4.71 (m, 11H, H-1A, H-1E, H-5D, H-5E, H-5F, H-3G, 5xCHPh), 4.69 - 4.30 (m, 25H, H-6D, H-3F, H-6G, Hallylcis-syn, 21xCHPh) 4.30 - 4.18 (m, 7H, H-3B, H-3C, H-4C, Hallyltrans, 3xCH_2Ph) 4.12 - 4.03 (m, 3H, H-3D, H-3E, H-5G) 4.02 - 3.42 (m, 22H, H-2A, H-2B, H-2C, H-2G, H-3A, H-4A, H-4B, H-4D, H-4E, H-4F, H-4G, H-5B, H-6B, H-5C, H-6A, 2xH-6C, H-6D, H-6G, 2xH-6F, Hallyl-cis), 3.39 (dd,$^3J_{2,3}$ = 10.0 Hz, $^3J_{1,2}$ = 3.2Hz, 1H, H-2F), 3.30 (dd, $^3J_{2,3}$ = 9.7 Hz, $^3J_{1,2}$ = 3.3Hz, 1H, H2-E), 3.05 (m, 3H, H6-B, 2xH6-E), 2.78 (m, 1H, Hallylcis-anti). ^{13}C-NMR (151 MHz, acetone-d_6) 183.5 (C=Pd), 142.1-139.8 (Cipso), 129.2-127.1 (CAr), 124.2 (N-CH=CH-N, A), 123.7 (N-CH=CH-N,D), 114,4 (CAllylmeso), 101.17 (C-1D), 101.12 (C-1E), 98.48x2 (C-1A, C-1F), 98.2 5 (C-1B) 97.3 (C-1C), 96.4 (C-1G), 84.0 (C-4F), 83.9 (C-3A), 83.5 (C-4E), 82.3 (C-4G), 82.1 (C-4C), 81.5x2(C-4B, C3/F), 81.3 (C-3G), 81.2-81.1 (2xC-2A/B/D, C-2G, C-3G, C-3B, C-3E/D), 81.0 (C-3E/D), 80.9 (C-3C), 80.6 (C-2E), 80.5 (C-2A/B/D), 79.8 (C-2F), 78.7 (C-2C), 74.8 (CAllylcis), 74.4 (C-4D), 73.7(C-5C), 73.6 (C-5B), 73.4 (C-5G), 73.3 (C-4A), 73.1 (C-5A), 72.5 (C-5F), 71.7 (C-5D), 71.5 (C-5E), 71.3 (C-6F), 70.8 (C-6C)70.7 (C-6G), 69.9 (C-6E), 69.3 (C-6A), 56.0 (C-6D), 53.1 (C-6A), 51.2 (CAllyltrans). HRMS (ESI): calculated for $C_{181}H_{189}ClN_2O_{33}PdNa$ $[M+Na]^+$ 3082.1828, found 3081.1738 err 1.3 ppm. Rf=0.35 (CyH:AcOEt 3:1)

(β-ICyD)PdCl$_2$(PhCN)

(**β-ICyD)**AgCl (227 mg, 73 μmol, 1eq) and bis(benzonitrile)palladium(II) chloride (28,8 mg, 73 μmol, 1eq) were weighed in a sealed tube and purged with Ar, then CH_2Cl_2 (2 mL) was added, and the reaction mixture was heated at 40°C for 30 minutes. The reaction was followed by Mass Spectrometry and TLC. Upon completion, silver salts were removed by filtration with a 0.2 μm PET filter and evaporated *in vacuo*. After silica gel filtration on a small column (CyH : EtOAc, 3 : 1) **(β-ICyD)**$PdCl_2$(PhCN) was obtained as a pale yellow foam (218mg, 94%). ^{1}H-NMR: (600 MHz, acetone-d_6): 7.80 - 7.76 (m, 2H, Hortho Benzonitrile), 7.75 - 7.70 (m, 1H, Hpara Benzonitrile), 7.62 - 7.57 (m, 2H, Hmeta Benzonitrile), 7.50 - 6.98 (m, 94H, HAr) 6.95 (, t, J = 7.7 Hz, 2H, HArmeta), 6.91 (d, J = 1.9 Hz, 1H, NH-CH=CH-NH), 6.77 (t, J = 6.7 Hz, 1H, HArpara) 6.70 (d, J = 1.9Hz, 1H, HImD), 6.02 (d, J = 3.8 Hz, 1H, H1-G), 5.90 (d, J = 3.8 Hz, 1H, H1-C), 5.89 - 5.77 (m, 3H, H5-D, H6-A, H6-D) , 5.73 - 5.63 (m, 3H, 2 x CHPh, H5-A), 5.35 (d, J = 11.4 Hz, 1H, CHPh), 5.29 - 5.16 (m, 5H, 3xCHPh, H1-D, H3-C), 5.00 (d, J = 3.2 Hz, 1H, H1-F), 4.98 - 4.82 (m, 10H, H3-G, H1-F, 8xCHPh), 4.77 (d, J = 3.3 Hz, 1H, H1-E), 4.75 - 4.25 (m, 38H, H1-A, H1-B, H3-B, H3-F, H5-B, H5-E, H5-F, H6-C, H6-G, 30xCHPh), 4.21 - 4.10 (m, 4H, H5-G, H3-A, H3-D, H3-E) 4.05 - 3.95 (m, 5H,H4-G, H4-C, H5-G, H5-C, CHPh), 3.92 - 3.78 (m, 6H, H4-B, H4-D,H4-E, H6-G, H6-D, H6-C) 3.77 - 3.67 (m, 5H, H2- G, H4-A, H6-A H6-B, H6.-B, H6-E, 2XH6-F), 3.65 (dd, J = 9.5, 3.8 Hz, 1H, H2-D), 3.58 (dd, J = 10.0, 8.1 Hz, 1H, H4-F), 3.48 (dd, J = 10.4, 3.8 Hz, 1H, H2-C), 3.42 (dd, J = 9.8, 3.3 Hz, 1H, H2-A), 3.38 - 3.32 (2 x dd, J = 10.0, 3.6 Hz, 2H H2-F, H2-B) 3.27 (dd, J = 10.0, 3.3 Hz, 1H, H2-E), 3.18 - 3.06 (m, 2H, H6-B, H6-E). ^{13}C-NMR (151MHz, acetone-d_6) 144.5 (C=Pd), 141.8-139.2 (Cipso), 133,9 (CBenzontrile meta) 132,9 (CBenzontrileOrtho), 130,3 (CBenzonitrile Para), 129,3-127,2 (CAr), 101,0 (C1-E), 99.3 (C1-D) 99.0 (C1-F), 98.3 (C1-B), 98.2 (C1-A), 98.1 (C1-G), 98.0 (C1-C), 83.9 (C4-F), 83.4 (C3-D), 83.3 (C3-A), 83.0 (C4-E), 82.6 (C4-G), 82.2 (C4-C), 82.0 (C2-D), 81.76 (C4-B), 81.71 (C2-A), 81.32 (C2-F), 81.30 (C4-E), 81.1 (C2-B), 80.85 (C3-B), 80.5 (C3-E), 80.0X2(C2-E, C3-G), 79.5(C3-C), 79.32 (C2-C), 78.54 (C2-G), 76.9x2, 76.7x2,76.7, 76.5, 75.6, 75.3 (7x CH2Ph), 74.6(C4-D), 74.4(C5-C), 74.0(C4-A),73.9 (CH2Ph), 73.8(C5-G), 73.8x3, 73.6, 73.5, 73.3, 73.2 (7xCH2Ph), 73.2 (C5-A), 73.0, 72.8 (2xCH2Ph), 72.5X2 (C5-B, C5-F), 71.7(C5-E), 71.4 (C6-C), 71.3(C5-D), 71.0 (C6-B), 70.6 (C6-F), 69.8 (C6-E), 69.7 (C6-B), 54.7 (C6-D), 54.1 (C6-A). HRMS (ESI): calculated for $C_{185}H_{189}Cl_2N_3O_{33}PdNa_2$ $[M+2Na]^{2+}$1549.5507 found 1549.5483 err 1.6 ppm. Rf = 0.39 (CyH : AcOEt 3 : 1)

(β-ICyD)PdCl$_2$(Pyr)

(β-ICyD)HCl (100 mg, 0.34 μmol), K_2CO_3 (64 mg, 2.76 μmol) and $PdCl_2(PhCN)_2$ (12.7 mg, 0.34 μmol) were weighted in a sealed tube and purged with Ar. Then, pyridine (1 mL) was added and the reaction mixture was stirred for 18 hours at 80 °C. After cooling down the mixture to room temperature, the solvent was evaporated and the product was filtrated on a silica gel column (CyH : AcOEt 5 : 1) affording **(β-ICyD)**$PdCl_2$(Pyr) as a pale

yellow foam (73 mg, 68%). ^{1}H NMR (600 MHz, Chloroform-d) δ 9.17 – 9.14 (m, 2H, $H_{orthoPy}$), 7.42 – 6.92 (m, 95H, H_{Arom}, H_{paraPy})), 6.81 (t, J = 7.4 Hz, 1H, H_{para}), 6.64 (t, J = 7.0 Hz, 2H,H_{metaPy}), 6.19 (d, J = 1.8 Hz, 1H, H_{ImidD}), 6.12 (t, J = 10.4 Hz, 1H, H5-D), 6.04 (d, J = 1.7 Hz, 1H, HImid-A), 5.97 (d, J = 4.2 Hz, 1H, H1-G), 5.89 (d, J = 3.9 Hz, 1H, H1-C), 5.74 – 5.67 (m, 2H, H6b-A, H6b-D), 5.52 (d, J = 11.0 Hz, 1H, CH2Ph), 5.43 (td, J = 10.4, 2.5 Hz, 1H, H5-A), 5.26 – 5.20 (m, 3H, 2xCH2Ph, H3-C), 5.14 (2xd, J= 11.0 Hz, 2H, 2xCH2Ph), 5.05 (d, J = 3.8 Hz, 1H, H1-D), 4.84 – 4.09 (m, 46H, H1-A, H1-B, H1-E, H1-F, H5-E, H5-F, H5-G, H5-B, H3-A, H3-B, H3-D, H3-F, H3-G, 23xCH2Ph), 4.06 (dd, J = 10.7, 3.9 Hz, 1H, H6a-G), 3.92 (m, 3H, H3-E, H5-C, H6b-C), 3.86 – 3.72 (m, 8H, H4-B, H4-C, H4-D, H4-E, H4-G, H6a-C, H6a-F, H6b-G), 3.69 (t, J = 9.4 Hz, 1H, H4-A), 3.64 (t, J = 9.1 Hz, 1H, H4-F), 3.62 – 3.55 (m, 3H, H2-G, H6b-F, H6a-E), 3.54-3.48 (m, 2H, H2-C, H2-D), 3.46 (dd, J = 13.2, 11.1 Hz, 1H, H6a-D), 3.41 – 3.27 (m, 5H, H2-A, H2-B, H2-E, H2-F, H6a-A), 3.06 (d, J = 11.1 Hz, 1H, H6b-E), 2.92 (dd, J = 11.3, 2.5 Hz, 1H, H6b-B), 2.77 (d, J = 10.7 Hz, 1H, H6a-B). ^{13}C NMR (151 MHz, Chloroform-d) δ = 153.1 (C=Pd), 151.96 ($C_{orthoPy}$), 140.4, 140.3, 140.2, 140.1, 134.0, 139.23, 139.22, 139.1, 139.05, 139.00, 138.95, 138.93, 138.89, 138.8, 138.7, 138.5, 138.35, 138.30, 138.15 (19xC_{Ipso}), 137.5 (C_{paraPy}), 128.50, 127.26-126.5 (C- H_{Arom}) 124.14 (C_{metaPy}), 123.3 (C_{ImidA}), 122.95 (C_{ImidD}), 100.4 (C1-E), 99.9 (C1-F), 98.3 (C1- D), 98.2 (C1-B), 97.8 (C1-C), 97.6 (C1-A), 97.1 (C1-G), 82.8 (C4-F), 82.2 (C4-C, C4-D), 82.1 (C3-D), 81.95 ?, 81.6 (C4-E), 81.10 (C2-D), 80.90 (C4-B), 80.8 (C2-A), 80.77 (C3-A,C3-G), 80.7 (C3-F), 80.2 (C3-E, C3-B) , 79.7 (C2-F), 79.55 (C2-B), 78.80 (C2-E), 78.6 (C2-G), 78.3 (C3-C), 78.2 (C2-C), 76.45, 76.34, 76.17, 76.08, 75.54, 74.66 (6xCH2Ph), 74.62 (C4-D), 74.41 (5C4-A), 74.20(CH2Ph), 73.80 (C5-C), 73.60, 73.43, 73.38, 73.33, 73.09, 73.01, 72.81, 72.64, 72.47 (11xCH2Ph), 72.26 (C5-G), 72.23 (CH2Ph), 71.7 (C5-A), 71.5 (C5-F), 71.16 (C5-B), 71.12 (C6-C), 70.7 (C5-D), 70.6 (C5-E), 70.0 C6-F, 69.68 (C6-G), 68.96 (C6-E), 68.93 (C6-B), 54.77 (C6-D), 53.79 (C6-A). HRMS (ESI): Calculated for $C_{183}H_{189}Cl_2N_3O_{33}PdNaK$ $[M+Na+K]^{2+}$ 1557.5377, found 1557.5403 err -1.7 ppm. Rf=0.42 (CyH:AcOEt 3:1)

(γ-ICyD)PdCl(η^3 allyl)

(**γ-ICyD)AgCl** (10mg, 2.8 μmol) and allylpalladium(II) chloride dimer (0.5 mg, 1.4 μmol) were weighed in a sealed tube and purged with Ar, then dry CH_2Cl_2 (1,5 mL) was added. The reaction mixture was stirred at room temperature for 30 minutes and followed by Mass Spectrometry and TLC, upon completion, silver salts were removed by filtration with a 0.2 μm PET filter, washed with CH_2Cl_2. After evaporation of the solvent under reduced pressure, **(γ-ICyD)PdCl(η^3 allyl)** complex (9 mg, 88%) was obtained as a yellow pale foam and characterized without any further purification as a mixture of two isomers in a 6 : 4 ratio. ^{1}H NMR (600 MHz, Acetone-d_6) δ 7.52 – 7.44 (m, 10H), 7.47 – 7.20 (m, 110H), 7.20 (s, 6H), 7.17 (ddd, J = 6.8, 4.9, 1.9 Hz, 20H), 7.17 – 7.07 (m, 10H), 7.10 – 6.97 (m, 10H), 6.81 (dt, J = 17.9, 7.5 Hz, 6H), 6.67 – 6.55 (m, 6H), 5.97 (d, J = 4.0 Hz, 1H), 5.91 – 5.82 (m, 6H), 5.78 – 5.69 (m, 3H), 5.56 (dd, J = 27.9, 10.8 Hz, 4H), 5.47 – 5.38 (m, 5H), 5.32 – 5.12 (m, 11H), 5.10 (dd, J = 7.2, 3.1 Hz, 4H), 5.08 – 4.79 (m, 25H), 4.79 – 4.68 (m, 9H), 4.70 – 4.21 (m, 85H), 4.20 – 3.28 (m, 68H), 3.29 – 3.06 (m, 10H), 3.02 (d, J = 12.0 Hz, 4H), 2.60 (d, J = 11.8 Hz, 2H, HAllylcis-anti(isomer a)), 2.34 (d, J = 11.7 Hz, 1H, HAllylcis-anti (isomer b)). ^{13}C NMR (151 MHz, Acetone) δ 182.6 (C=Pd), 182.5, (C=Pd), 142.6, 141.6, 141.4, 141.0, 140.7, 140.6, 140.4, 140.1, 139.9, 139.8, 139.7, 139.3, 139.1, 137.6 (Cipso), 129.5, 129.4, 129.3, 129.3, 129.2, 129.2, 129.1, 129.1, 129.0, 129.0, 128.9, 128.8, 128.8, 128.7, 128.7, 128.5, 128.3, 128.3, 128.2, 128.2, 128.2, 128.1, 128.0, 128.0, 127.9, 127.8, 127.7, 127.6, 127.3, 127.1, 126.9, (CHAr) 124.1, 123.8, 123.5 (3signals from CIm) 116.1 (Cmeso, isomer b), 115.1 (Cmeso isomer a), 100.4, 100.1, 99.8, 99.7, 99.0, 99.0, 99.0, 98.8, 98.6, 97.8, 93.6, 93.6, 93.5, 93.5 (14 signals corresponding to C1), 83.9, 83.8, 83.2, 82.2, 82.0, 81.7, 81.6, 81.5, 81.4, 81.1, 80.8, 80.7, 80.4, 80.1, 79.6, 79.2, 77.7, 77.6, 77.5, 77.1, 76.9, 76.8, 76.5, 74.1, 74.0, 74.0, 73.9, 73.8, 73.6, 73.5, 73.3, 73.3, 73.3, 73.2, 73.1, 73.0, 72.8, 72.7, 72.3, 72.1, 72.0, 71.8, 71.4, 71.2, 71.1, 70.5, 70.4, 70.2, 69.5, 69.5 (C2, C3, C4, C5, CPhCHH), 53.2, 52.9, 53.8, 54.0 (4x C6A,E), 44.9(Ccis, isomer a), (Ccis, isomer b). MS (ESI): Calculated for $C_{208}H_{217}ClN_2O_{38}PdNa$ $[M+Na]^{+}$ 3514.3768, found 3514.5314. Rf=0.34 (CyH:AcOEt 3:1)

(γ-ICyD)PdCl$_2$(PhCN)

(**γ-ICyD)**AgCl (10 mg, 2.8 μmol) and bis(benzonitrile) palladium(II) chloride (1.1 mg, 2.8 μmol) were weighed in a sealed tube and purged with Ar, then, dry DCM (1 mL) was added. The reaction mixture was heated at 40 °C for 30 minutes and monitored by Mass Spectrometry and TLC. Upon completion, silver salts were removed by filtration with a 0.2 μm PET filter, washed with CH_2Cl_2 and evaporated in vacuo affording **(γ-ICyD)**$PdCl_2$(PhCN) complex (9mg, 88%) characterized without further purification.

^{1}H NMR (600 MHz, Acetone-d6) δ 7.78 (dd, J = 8.2, 1.4 Hz, 2H, H_{PhCN}),, 7.65 (m, 1H, H_{PhCN}), 7.60 (m, 1H, H_{PhCN}), 7.46 – 6.97 (m, 106H, H_{Ar}), 6.88 (t, J = 8.2, 2H, H_{Ar}), 6.73 (s, 2H, N-CH=CH-N), 6.03 – 5.91 (m, 4H, 2 x H-1D,H, 2 x H-6A,E), 5.58 (d, $^{2}J_{PhCHH}$ = 12.1 Hz, 2H, PhCHH), 5.49 (d, $^{2}J_{PhCHH}$ = 10.6 Hz, 2H, 2 x PhCHH), 5.34 (d, $^{3}J_{PhCHH}$ = 11.3

Hz, 2H, PhCHH), 5.17 – 5.05 (m, 4H, 2 x H-1A,E, 2 x H-5A,E), 4.93 (2 x d, ^{3}J = 3.3 Hz, 4H, H-1B,F, H-1C,G), 4.87 (2 x d, $^{3}J_{PhCHH}$ = 11.4 Hz, 4H. 2 x PhCHH), 4.80 - 4.71 (m, 6H, 6 x PhCHH), 4.68 – 4.36 (m, 28H, 2 x H-3D,H, 16 PhCHH), 4.32 – 4.27 (m, 4H, 2 x H-3C,G, 2 x H6-D,H), 4.25 – 4.13 (m, 10H, 2 x H-3A,E, 2 x H-5B,F, 2 x H-5C,G, 4 x PhCHH), 4.05 (t, J = 9.4 Hz, 2H, H-3B,F), 3.93 (m, 4H, H-6C,G), 3.90 – 3.82 (m, 6H, 2 x H-4B,F, 2 x H-4D,H, 2 x H-6D,H), 3.80 – 3.73 (m, 4H, 2 x H-5D,H, 2 x H-4A,E), 3.70 (t, $^{3}J_{4,5}$ = $^{3}J_{4,3}$ 9.2 Hz, 2H, 2 x H-4C,G), 3.61 (bt, 2H, 2 x H-6A,E), 3.55 (dd, $^{3}J_{2,3}$ = 10.2 Hz, $^{3}J_{2,1}$ = 3.7 Hz, 2H, 2 x H-2D,H), 3.53 – 3.50 (m, 1H, 2 xH-2A,E), 3.42 – 3.30 (m, 6H, 2 x H-2C,G, 2 x H-2B,F, 2 x H-6B,F), 3.09 (bd, $^{3}J_{6a,6b}$ = 11.7 Hz, 2H, 2 x H-6B,F). ^{13}C NMR (151 MHz, Acetone-d_6) δ 144.6 (C=Pd), 144.6 - 139.2 (C_{ipso}), 133.9 - 127.0 ($CH_{Ar,\ CHArPhCN}$), 125.2 (N-CH=CH-N), 99.1 (C-1C,G), 98.6 (C-1A,E, C-1B,F), 94.8 (C-1D,G), 83.1 (C-4D,H, C-2D,H), 82.9 (C-4C,G), 82.2 (C-3A,E), 81.7(C-3C,G), 81.5 (C-2B,F, C-3B,F), 81.5 (C-2A,E), 80.6 (C-2B,F), 80.4 (C-2C,G), 80.0 (C-2D,H, C-3D,H), 77.5 (CHHPh), 76.9 (CHHPh), 76.6 (CHHPh), 74.2 (CHHPh), 73.8 (CHHPh), 73.8 (CHHPh), 73.5 (C-4A,E, C-5D,H), 73.1 (CHHPh), 73.0 (CHHPh), 72.9 (C-5C,G), 72.8 (CHHPh), 72.7(CHHPh), 72.4, 72.1 (C-5A,E), 71.9 (C-6B,F), 71.2 (C-2C,G), 70.8 (C-2D,H), 69.9 (CHHPh), 68.8 (CHHPh), 68.3 (CHHPh), 66.8 (CHHPh), 66.4 (C-2B,F), 54.1(C-6A,E). HRMS (ESI): Calculated for $C_{205}H_{212}N_2O_{38}PdCl_2Na$ [M-(C_6H_5-CN)+Na]$^{+}$, 3508.3027 found 3508.3001 err 0.7 ppm. Rf = 0.37 (CyH : AcOEt 3 : 1)

(γ-ICyD)PdCl$_2$(pyr)

(γ-ICyD)HCl (50 mg, 0.14 µmol), K_2CO_3 (30 mg, 1.96 µmol) and $PdCl_2(PhCN)_2$ (5.9 mg, 0.14 µmol) were weighed in a sealed tube and purged with Ar. Then pyridine (1 mL) was added and the reaction mixture was stirred for 18 h at 80 °C. After cooling down the mixture to room temperature, the solvent was evaporated under reduced pressure and the product was filtrated on a silica gel column (CyH:AcOEt 5:1) affording **(γ-ICyD)**$PdCl_2$(pyr) as a pale yellow foam (47 mg, 88 %). ^{1}H NMR: (600 MHz, Chloroform-d) δ = 8.57 (d, 2H, J=5.5, 2 x H$_{orthoPy}$), 7.47 (d, 4H, J = 7.7, 4 x H$_{Bn}$), 7.43 (d, 4H, J = 7.5 Hz, 4 x H$_{orthoBn}$), 7.31 – 7.02 (m, 92H, 94 x H$_{Ar}$), 7.04 – 6.92 (m, 6H, H$_{Ar}$), 6.84 (m, 4H, 4 x H$_{Ar}$), 6.72 (t, 2 H,J = 7.5 Hz, H$_{Ar}$), 6.10 (s, 1H, N-CH=CH- N), 5.97 (m, 3H, 2 x H-1D,H, H$_{paraPy}$), 5.78 (d, 2H, $^{2}J_{H6a-H6b}$ = 13.3 Hz, H-6A,E), 5.53 (t, 1H J = 6.7 Hz, CH$_{metaPy}$), 5.49 (d, 2H, J = 10.0 Hz, 2 x PhCHH), 5.33 (d, 2H, J = 11.1Hz, 2 x CHHPh), 5.08 (t, 2H, $^{3}J_{H5-H6}$ =-$^{3}J_{H5-H4}$ = 10.4 HZ, 2 x H-5A,D), 4.96 – 4.89 (m, 4H, H-1A,D, 4 x PhCHH), 4.84 – 4.75 (m, 6H, 4 x PhCHH, 2 x H-1B,F), 4.78 (d, 2H, $^{2}J_{H1-H2}$ = 3.3 Hz, 2 x H-1C,G), 4.64 – 4.50 (m, 10H, 10 x PhCHH), 4.52 – 4.40 (m, 10H, 10 x PhCHH), 4.35 – 4.09 (m, 22H, 2xH-3A,D, 2 x H-3B,F, 2 x H-5B,F, 2 x H-3C,G, 2 x H-3D,H, 2 x H-6D,H, 10 x PhCHH), 4.00 (dd, 2H $^{3}J_{H5-H4}$ = 10.0 Hz, $^{3}J_{H5-H6}$ = 4.6, 2 x H-5C,G), 3.84 (m, 8H, 4 x H-6C,G, 2 x H-6D,H, 2 x H-4B,F), 3.75 (t, 2H $^{3}J_{H4-H5}$ = $^{3}J_{H4-H3}$ = 9.2 Hz, 2 xH-4D,H), 3.69 – 3.62 (m, 4H, 2 x H-4C,F, H-4A,E), 3.58 (dd, $^{3}J_{H5-H4}$ = 9.9 Hz, $^{3}J_{H5-H6}$ = 3.9 Hz, 2 x H-5D,H), 3.49 — 3.42 (m,6H, 2xH-2B,F, 2 x H-2A,E, 2 x H2-D,H), 3.35 – 3.21 (m, 6H, 2 x H-2C,G, 2 x H-6A,D, 2 x H-6B,F), 2.95 (d, 2H, $^{2}J_{PhCHH}$ = 11.7 Hz, PhCHH), 2.89 (d, 2H, $^{2}J_{H6a-H6a}$=11.0, 2 x H6-B,F). ^{13}C NMR: (151 MHz, Chloroform-d) δ = 155.9 (C=Pd), 151.7 (C$_{orthoPy}$), 140.7, 140.1, 140.0, 139.1, 139.00, 138.98, 138.9, 138.8, 138.7, 138.6, 138.30 (11 x Cipso), 136.6 (C$_{paraPy}$), 128.8 — 125.9 (CH$_{Ar}$), 123.4 (CH$_{meta}$), 122.9 (N-CH=CH-N), 98.9 (C-1C,G), 98.6 (C-1B,F), 98.2 (C-1A,E), 93.1(C-1D,H), 82.0 (C-4C,G), 81.9 (C-4D,H), 81.4 (C-3A,E), 80.9 (C-3C,G), 80.8 (C-3B,F), 80.7 (C-2A,E), 80.7 (C-4B,F), 79.3 (C-2D,H), 79.2 (C-2B,F), 78.9 (C-3D,H), 78.9 (C-2C,G), 77.4, 77.0, 76.2, 74.9, 73.8, 73.5, 73.4, 73.2, 72.7 (9 X PhCHH), 72.4 (C-5D,H), 72.2, 72.1 (2 x PhCHH), 71.8 (C-5C,G), 71.5, 71.4 (C-4A,E, C-5A,E), 70.7 (C-5B,F), 70.4(C-6C,G), 69.7 (C-6D,H), 69.3 (C-6B,F), 53.2 (C-2A,E). HRMS (ESI): Calculated for $C_{210}H_{217}Cl_2N_3O_{38}PdNa_2$ [M+2Na]$^{2+}$ 1805.1689, found 1805.1566 err 6.8 ppm. Rf = 0.35 (CyH : AcOEt 3 : 1)

General procedure for (ICyD)Pd-catalyzed Allylation of aldehydes

In a sealed tube **(ICyD)**PdCl(allyl) (4.0 µmol), PPh_3 (1.05 mg 4.0 µmol) were dissolved in THF (1.5 mL) under Ar. Then, 4-Bromobenzaldehyde **1** (37 mg, 0.200µmol) and allyl acetate **2** (24 mg, 240 µmol) were added. Then, a solution of $ZnEt_2$ in hexanes (700 µL, 700 µmol) was added dropwise. The reaction mixture was monitored by TLC. Upon completion, a saturated aqueous solution of NH_4Cl (4mL) was added dropwise and vigorously stirred for 30 minutes. The product was extracted with Et_2O (2 x 10 mL), dried with Na_2SO_4 and evaporated in *vacuo.* The crudemixture was purified by silica gel flash chromatography (CyH:AcOEt 95:5) affording **5**.

General procedure for substrate selection in (ICyD)Pd-catalyzed Allylation of aldehydes

(ICyD)PdCl(allyl) (4.0 µmol) and PPh_3 (1.05 mg 4.0 µmol) were weighted in a sealed tube and purged with Ar, then, THF (1.5 mL) was added. After stirring 10 minutes 4-Bromobenzaldehyde **1** (37 mg, 0.200 µmol), allyl acetate **2** (12 mg, 120 µmol) and cynnamyl acetate **3** (20 µL, 120 µmol) were added. Then, a solution of $ZnEt_2$ in hexanes (700 µL, 700 µmol) was added dropwise and the reaction mixture was stirred at room temperature

overnight. Saturated aqueous solution of NH_4Cl (4mL) was added dropwise and vigorously stirred for 30 minutes. The product was extracted with Et_2O (2 x 10 mL), dried with $MgSO_4$ and evaporated in vacuo. The crude mixture was analyzed by NMR. By integration of the internal vinyl proton conversion and ratio of **5:6** was obtained.

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References

[1] Selected recent reviews: M. Raynal, P. Ballester, A. Vidal-Ferran, P. W. N. M. van Leeuwen, *Chem. Soc. Rev.* **2014**, *43*, 1734-1787; S. H. A. M. Leenders, R. Gramage-Doria, B. de Bruin, J. N. H. Reek, *Chem. Soc. Rev.* **2015**, *44*, 433-448; J.-N. Rebilly, B. Colasson, O. Bistri, D. Over, O. Reinaud, *Chem. Soc. Rev.* **2015**, *44*, 467-489; C. J. Brown, F. D. Toste, R. G. Bergman, K. N. Raymond, *Chem. Rev.* **2015**, *115*, 3012−3035; T. Iwasawa, *Tetrahedron Lett.* **2017**, *58*, 4217–4226; S. Roland, J. Meijide Suarez, M. Sollogoub, *Chem. Eur. J.* **2018**, *24*, 12464-12473; Y. Fang, J. A. Powell, E. Li, Q. Wang, Z. Perry, A. Kirchon, X. Yang, Z. Xiao, C. Zhu, L. Zhang, F. Huang, H.-C. Zhou, *Chem. Soc. Rev.* **2019**, *48*, 4707–4730; K. Wang, J. H. Jordan, X.-Y. Hu, L. Wang, *Angew. Chem. Int. Ed.* **2020**, *59*, 13712-13721; A. B. Grommet, M. Feller, R. Klajn, *Nat. Nano.* **2020**, *15*, 256–271; M. Morimoto, S. M. Bierschenk, K. T. Xia, R. G. Bergman, K. N. Raymond, F. D. Toste, Nat. Catal. **2020**, *3*, 969–984; Z. Kaya, E. Bentouhami, K. Pelzer, D. Armspach, *Coord. Chem. Rev.* **2021**, *445*, 214066; G. Olivo, G. Capocasa, D. Del Giudice, O. Lanzalunga, S. Di Stefano, *Chem. Soc. Rev.* **2021**, *50*, 7681-7724.

2 F. Cramer, *Chem. Ber.* **1953**, *86*, 1576-1581.

[3] E. Engeldinger, D. Armspach, D. Matt, *Chem. Rev.* **2003**, *103*, 4147-4174.

[4] I. Tabushi, *Acc. Chem. Res.* **1982**, *15*, 66-72;

[5] R. Breslow, L. E. Overman, *J. Am. Chem. Soc.* **1970**,*92*, 1075-1077.

[6] R. Breslow, S. D. Dong, *Chem. Rev.* **1998**, *98*, 1997-2012.

[7] R. Gramage-Doria, D. Armspach, D. Matt, *Coord. Chem. Rev.* **2013**, *257*, 776-816.

[8] M. T. Reetz, J. Rudolph, *Tetrahedron: Asymm.* **1993**, *4*, 2405-2406; M. T. Reetz, S. R. Waldvogel, *Angew. Chem. Int. Ed.*, **1997**, *36*, 865-867; Y. Tung Wong, C. Yang, K.-C. Ying, G. Jia, *Organometallics* **2002**, *21*, 1782–1787; E. Engeldinger, L. Poorters, D. Armspach, D. Matt, L. Toupet, *Chem. Commun.*, **2004**, 634-635 ; D. Ngan Tran, F.-X. Legrand, S. Menuel, H. Bricout, S. Tilloy, E. Monflier, *Chem. Commun.*, **2012**, *48*, 753-755.

[9] S. Guieu, E. Zaborova, Y. Blériot, G. Poli, A. Jutand, D. Madec, G. Prestat, M. Sollogoub, *Angew. Chem. Int. Ed*. **2010**, *49*, 2314-2318; E. Zaborova, J. Deschamp, S. Guieu, Y. Blériot, G. Poli, M. Ménand, D. Madec, G. Prestat, M. Sollogoub, *Chem. Commun.* **2011**, *47*, 9206-9208

[10] C. Yang, Y. K. Cheung, J. Yao, Y. T. Wong, G. Jia, *Organometallics* **2001**, *20*, 424–429; R. Heck, A. Marsura, *Tetrahedron Lett.* **2004**, *45*, 281-284; D. Sechet, Z. Kaya, T.-A. Phan, M. Jouffroy, E. Bentouhami, D. Armspach, D. Matt, L. Toupet, *Chem. Commun.*, **2017**, 53, 11717-11720.

[11] B. Benmerad, P. Clair, D. Armspach, D. Matt, F. Balegroune, L. Toupet, *Chem. Commun.* **2006**, *25*, 2678-2680

[12] F-X. Legrand, M. Ménand, M. Sollogoub, S. Tilloy, E. Monflier, *New J. Chem.* **2011**, *35*, 2061-2065; M. Guitet, F. Marcelo, S. Adam de Beaumais, Y. Zhang, J. Jiménez-Barbero, S. Tilloy, E. Monflier, M. Ménand, M. Sollogoub, *Eur. J. Org. Chem.* **2013**, 3691-3699.

[13] M. Guitet, P. Zhang, F. Marcelo, C. Tugny, J. Jiménez-Barbero, O. Buriez, C. Amatore, V. Mouriès-Mansuy, J.-P. Goddard, L. Fensterbank, Y. Zhang, S. Roland, M. Ménand, M. Sollogoub, *Angew. Chem. Int. Ed.* **2013**, *52*, 7213-7218.

[14] G. dos Passos Gomes, G. Xu, X. Zhu, L.-M. Chamoreau, Y. Zhang, O. Bistri-Aslanoff, S. Roland, I. V. Alabugin, M. Sollogoub *Chem. Eur. J.* **2021**, *27*, 8127-8142.

[15] P. Zhang, C. Tugny, J. Meijide Suárez, M. Guitet, E. Derat, N. Vanthuyne, Y. Zhang, O. Bistri, V. Mouriès-Mansuy, M. Ménand, S. Roland, L. Fensterbank, M. Sollogoub, *Chem* **2017**, *3*, 174-191.

[16] C. Tugny, N. del Rio, M. Koohgard, N. Vanthuyne, D. Lesage, K. Bijouard, P. Zhang, J. Meijide Suárez, S. Roland, O. Bistri-Aslanoff, M. Sollogoub, L. Fensterbank, V. Mouriès-Mansuy, *ACS Catal.* **2020**, *10*, 5964-5972

[17] X. Zhu, G. Xu, L.-M. Chamoreau, Y. Zhang, V. Mansuy, L. Fensterbank, O. Bistri-Aslanoff, S. Roland, M. Sollogoub, *Chem. Eur. J.* **2020**, *26*, 15901-15909.

[18] P. Zhang, J. Meijide Suarez, T. Driant, E. Derat, Y. Zhang, M. Ménand, S. Roland, M. Sollogoub, *Angew. Chem. Int. Ed.* **2017**, *56*, 10821-10825; Z. Wen, Y. Zhang, S. Roland, M. Sollogoub, *Eur. J. Org. Chem.* **2019**, 2682-2687.

[19] G. Xu, S. Leloux, P. Zhang, J. Meijide Suárez, Y. Zhang, E. Derat, M. Ménand, O. Bistri-Aslanoff, S. Roland, T. Leyssens, O. Riant, M. Sollogoub, *Angew. Chem. Int. Ed.* **2020**, *59*, 7591-7597

[20] D. Matt, J. Harrowfield, *ChemCatChem*, **2021**, *13*, 153-168; I. Martín-Torres, G. Ogalla, J.-M. Yang, A. Rinaldi, A. M. Echavarren, *Angew. Chem. Int. Ed.* **2021**, *60*, 9339-9344; G. Cera, G. Giovanardi, A. Secchi, A. Arduini, *Chem. Eur. J.* **2021**, *27*, 10261-10266.

[21] *Angew. Chem. Int. Ed.*, **2016**, *55*, 8367-8370.

[22] a) S. Roland, J. Meijide Suárez, M. Sollogoub, *Chem. Eur. J.*, **2018**, *24*, 12464-12473; b) H. Sak, M. Mawick, N. Krause, *ChemCatChem* **2019**, *11*, 5821-5829; c) Z. Kaya, L. Andna, D. Matt, E. Bentouhami, J.-P. Djukic, D. Armspach, *Eur. J. Org. Chem.*, **2019**, 4528-4537.

[23] S. Gaillard, A. M. Z. Slawin, A. T. Bonura, E. D. Stevens, S. P. Nolan *Organometallics* **2010**, *29*, 394-402.

[24] C. Topf, C. Hirtenlehner, M. Zabel, M. List, M. Fleck, U. Monkowius, *Organometallics* **2011**, *30*, 2755–2764

[25] S. Roland, M. Audouin, P. Mangeney, *Organometallics*, **2004**, *23*, 3075-3078.

[26] M. S. Viciu, O. Navarro, R. F. Germaneau, R. A. Kelly, W. Sommer, N. Marion, E. D. Stevens, L. Cavallo, S. P. Nolan. *Organometallics*, **2004**, *23*, 1629-1635.

[27] a) C. Valente, S. Çalimsiz, K. H. Hoi, D. Mallik, M. Sayah, M. G. Organ, *Angew. Chem. Int. Ed.*, **2012**, *51*, 3314-3332; b) M. G. Organ, S. Avola, I. Dubovyk, N. Hadei, E. A. B. Kantchev, C. J. O Brien, C. Valente, *Chem. Eur. J.,* **2006**, *12*, 4749-4755.

[28] P. G. A. Kumar, P. Dotta, R. Hermatschweiler, P. S. Pregosin, *Organometallics* **2005**, *24*, 1306-1314.

[29] S. Filipuzzi, P. S. Pregosin, A. Albinati, S. Rizzato, *Organometallics*, **2008,** *27*, 437-444

[30] a) K. Yasui, Y. Goto, T. Yajima, Y. Taniseki, K. Fugami, A. Tanaka, Y. Tamaru, *Tetrahedron Lett.*, **1993**, *34*, 7619-7622; b) N. T. Patil, Y. Yamamoto, *Jordan J. Chem.* **2006**, *1*, 13-23; ; c) K. Spielmann, G. Niel, R. Marcia de Figueiredo, J.-M. Campagne, *Chem. Soc. Rev.*, **2018**, *47*,1159-1173.

[31] *For examples, see:* N. T. Barczak, R. E. Grote, E. R. Jarvo, *Organometallics*, **2007**, *26*, 4863-4865; A. Flahaut, K. Toutah, P. Mangeney, S. Roland, *Eur. J. Inorg. Chem*., **2009**, *35*, 5422-5432.

[32] W. Wang, T. Zhang, M. Shi, *Organometallics*, **2009**, *28*, 2640-2642; L. Faraji, K. Jadidi, B. Notash, *Tetrahedron Lett.*, **2014**, *55*, 346-350.

[33] *For examples of enantioselective versions with other ligands, see:* G. Zanoni, A. Pontiroli, A. Marchetti, G. Vidari, *Eur. J. Org. Chem.* **2007**, 3599-3611; M. Yus, J. C. González-Gómez, F. Foubelo, *Chem. Rev.*, **2011**, *111*, 7774-7854.

[34] M. L. Merlau, M. Del P. Mejía, S. T. Nguyen, J. T. Hupp, *Angew. Chem. Int. Ed.* **2001,** *40,* 4239-4242; C. Gibson, J. Rebek Jr, *Org. Lett.* **2002**, *4*,1887-1890; D. H. Leung, R. G. Bergman, K. N. Raymond, *J. Am. Chem. Soc.* **2007,** *129,* 2746-2747; B.Y. Wang, T. Zudovic, D. A. Turner, C. M. Hadad, J. D. Badjic, *J. Org. Chem.,* **2012,** *77,* 2675-2688; A. Carvazan, J. N. H. Reek, F. Trentin, A. Scarso, G. Strukul, *Catal. Sci. Technol.,* **2013,** *3,* 2898-2901; M. Otte, P. F. Kuijpers, O. Troeppner, I. Ivanović-Burmazovic, J. N. H. Reek, B. de Bruin, *Chem. Eur. J.* **2014**, *20* , 4880-4884; M. Otte, ACS Catal. **2016**, *6*, 6491-6510; P. F. Kuijpers, M. Otte, M. Dürr, I. Ivanovic-Burmazovik, J. N. H. Reek, B. De Bruin, *ACS Catal.* **2016,** *6,* 3106-3112; T. Chavagnan, C. Bauder, D. Sémeril, D. Matt, L. Toupet, *Eur. J. Org. Chem.* **2017**, 70-76.

Cavity-controlled coordination of square planar metal complexes and substrate selectivity by NHC-capped cyclodextrins (ICyDs)

J. Meijide Suárez, O. Bistri-Aslanoff, S. Roland*, M. Sollogoub*

The formation of encapsulated square planar Au^{III} and Pd^{II} complexes is only possible in the largest cyclodextrin cavities. An unexpected reversal of the ligand was observed with smaller cyclodextrin. The size of the cavity was also found to control the Au^{I} → Au^{III} oxidation. Finally, these ligands could discrimate between different substrates in a catalytic reaction.