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Chemo-Divergent and Regioselective Branched Cross-Hydroalkenylation of Electron-Deficient Olefins and Vinylarenes Directed by (NHC)Ni(II) Catalysts.

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Abstract:

Catalytic methods for synthesizing highly substituted olefins are crucial for fine chemical and polymer production, yet alkene insertion systems featuring two highly competitive directing effects often scramble the outcome, and strategies to distinguish these effects remain underdeveloped. Here, we present a straightforward chemodivergent and regioselective cross-hydroalkenylation of acrylates and vinylarenes, enabling intermolecular access to distinct conjugated olefin isomers that were previously inaccessible from those abundant substrate classes directly. Our investigations reveal that divergence arises from two sequential, redox-neutral insertion steps, which overcome intrinsic boundaries imposed by a common olefin intermediate formation, oxidative addition, or isomerization. Unlike tactics that rely on varying prefunctionalized substrate pairs, our (NHC)Ni(II)-directed method exploits catalyst-controlled responses to polarized olefin hydrometallation and carbometallation. The green synthesis has instant utility in drug synthesis and in the preparation of electron-deficient, branched allylic centers with up to 97% e.e.. This strategy also extends to vinylBpin and vinylsiloxanes, significantly expanding the scope of divergent olefin synthesis.

Introduction

Hydrovinylation (HV)[1-4] and cross-hydroalkenylation (HA)[5-12] are fundamental transformations for the preparation of highly substituted olefins. These tools complement olefin cross-metathesis[13], reductive cross-coupling[14-17] and acid-catalyzed 1,4-addition of electron-deficient olefin[18,19] by enabling atom-economical access to diverse carboskeletons and distinct olefin structures from two substrate pools. Advances employing Ru, Co, Ir, and Ni hydride catalysts with tailored ligand environments have expanded the scope[20-29], delivering exceptional chemo- and regio-selectivity and high enantioselectivity (Fig. 1a–c). Besides, chain-walk processes[30-37] and P ligand-mediated oxidative cross-dimerization have enabled regiodivergent olefin insertions/additions (Fig. 1d)[38,39]. Chemodivergent cross-HA, however, remains rare[40,41]. Systems featuring strongly competing directing effects, such as benzylic stabilization and electron-deficient substituents, frequently suffer from selectivity erosion, and effective strategies to differentiate these effects are underdeveloped (Fig. 1e)[42]. Consequently, most of the related chemodivergent syntheses are guided by a more reactive substrate, which first engages with the catalyst to form a common intermediate. This intermediate is then diverted in subsequent steps, such as oxidative cycloisomerization of 1,6-enynes, by using different ligands, olefins, or even distinct metal centers[39,43-50] (Fig. 1f). And the current HA solutions for accessing alternate isomers typically rely on redox-active cycles involving prefunctionalized grips like alkenyl halides. This gap motivates the development of methods that can response chemodivergently and regioselectively to hydrometallation (HM) and carbometallation (CM) preference within a given set of substrates. Here we present a [(NHC)Ni(allyl)Cl]-catalyzed (NHC = N-heterocyclic carbene) strategy that enables chemodivergent and regioselective cross-HA by reversing the donor/acceptor roles of the same substrate pairs under redox-neutral conditions (Fig. 1g, tail-to-head (t-h), tail-to-tail (t-t), and head-to-tail (h-t) cross-HA). Unlike other distinguish divergent alkene synthesis methodologies,[40,41] our approach exploits two discrete intermolecular insertion events at the (NHC)Ni(II) center (Fig. 1g), thereby avoiding redox-active pathways and saving substrates that are vulnerable to oxidation or elimination.

Results

System development

Our investigation commenced with [(NHC)Ni(allyl)Cl] as catalyst (Fig. 2), styrene **1a** and methyl acrylate **2a** as pair (Fig. 3). We hypothesized that an optimal β-/γ-heteroatom interactions with the (NHC)Ni(II) catalyst could override benzylic stabilization effects, thereby modulating HM chemo- and regio-selectivity (branched HM of **1a** vs. linear HM of **2a**, *b*-/*l*-HM). Next, by either aligning or opposing the **2a** polarization direction with sterically small or bulky NHCs, we anticipate a switch in substrate insertion chemoselectivity during CM step, favoring a high cross/homo-selectivity (Fig. 1g, path i-iii).

Systematic NHC screening identified two distinct catalyst classes: (i) bulky and symmetric NHCs (**L1**–**L5**) favored chemo- and regioselective *l*-HM of acrylate **2a** over styrene **1a**, affording homoallyl ester **3aa** with progressively higher *l*-over-*b*-HM selectivity (**L1**-**L5**, as reflected by **3**:**4** from 55:45 to >95:5); and (ii) sterically adaptive cores (**L6**–**L7**) or less-substituted NHCs (**L8**–**L9**) restored benzylic stabilization-directed *b*-HM of styrene (**L6**-**L11**), affording γ-branched α,β-unsaturated ester **5aa** (Fig. 3, see Fig. 2 for homo-HA products[51,52] and NHC structures). This selectivity swap correlates primarily with changes in NHC percentage buried volume (%V_{bur}). For 5-membered ring NHCs, %V_{bur} values derived from (NHC)AuCl models[53-55] at 2.00 Å show that **L1**-**L5** span 36.5-49.0%, whereas **L8**-**L9** fall within 34.5-27.5% range, showing that steric effects dominate (as **L1**-**L5**/**L8**-**L9** share similar electronic profile, A_1 CO ≈2051 cm^{-1} for [(NHC)Ni$(CO)_3$])[56].

Ring-expanded NHCs **L6**-**L7** exhibit even higher %V_{bur} values but reduced conformational rigidity due to enhanced internal rotation and lower symmetry[57-59], providing an alternative way to favor formation of **5**. A third strategy to promote high selectivity for **5** involves modifying the *N*-aryl substitution pattern. Chiral NHCs **L10**-**L11**, despite their steric bulk, offer open quadrants that relieve steric repulsions in the *b*-HM of **1a** and in *l*-CM of **2a**. This design enabled efficient synthesis of (*R*)-**5aa** using the C_2 symmetric chiral NHC **L11** bearing a single *ortho*-substituted *N*-aryl, analogous to **L9** (>95% yield, 97% e.e. by chiral HPLC). The absolute configuration was assigned by comparison with reported optical rotation (see SI for details). Moreover, regioselectivity of olefins on **3**-**6** was confirmed by comparison with authentic samples using crude ^{1}H NMR analysis, and no additional olefin isomers were detected. This one-step cross-HA therefore streamlines access to motifs in many pharmacologically important scaffolds, like Enterocin[60], Baccharisketone[61], Curcumene, Lacvigatin, ar-Himachalene, and Erogorgiaene[62-66]. It also replaces multistep routes based on Claisen rearrangement of branched allyl alcohol[67], allylic substitution-

olefin metathesis from acrylates[68], and convergent allylic substitution from alkynoates[66]. Importantly, the neutral conditions suppress the acid-catalyzed linear-dimerization of **1a** and base-promoted MBH-like reactivity of **2a**[69] (e.g. by P and N ligand dissociation related organocatalysis). In short, this NHC-substrate cooperation shifts the paradigm away from the traditional t-t and t-h selectivities prevalent in Ni/Pd chemistry, as well as the formal homo-head-to-head (h-h) and t-h selectivities in acidic and basic conditions. It enables access to previously unexplored h-t and alternate t-h pathways and delivers mutually exclusive product sets: no **5aa**/**6aa** by **L1**-**L5**, and no **3aa**/**4aa** by **L6**-**L9** and **L11**, representing a divergent shift from one to another out of 16 isomers.

Scope exploration

Next, the two highly chemo- and regio-selective HM strategies of acrylates and styrenes were applied for expanding the h-t and t-h cross-HA scope and applications (Fig. 4a-b). First, **2a** remained as a highly competent chemo- and regio-selective HM director in the presence of other compelling effects like steric bias and hemilabile groups under the actions of the **L4–L5** catalysts, accommodating aryl- (Fig. 4a1, electronic activated, fused rings), alkyl- (Fig. 4a2, linear and branched), hetero- (Fig. 4a2, O/N-allyl and homoallyl), Bpin- (Bpin = pinacol boronate group)(Fig. 4a3, allyl and vinyl) substituted olefins, all furnishing **3** in good yield and high selectivity (**3**:**4** up to 94:6, no **5** detected by NMR). Similarly, other acrylates (**2b**–**2e**) were tolerated, producing branched γ,δ-unsaturated esters (Fig. 4a3). Hence, this h-t HA directly enables both aromatic and aliphatic terminal olefins[70] for the analogous conjugated additions of 2-alkenylmetals to α,β-unsaturated esters, free it from the risk to nucleophilic substitutions and redox-active side reactions at allylic position. On the other hand, the sterically adaptive **L11**-directed chemo- and enantio-selective *b*-HM strategy maintained at high levels in general for a broad range of aromatic acceptors (Fig. 4b, **1a-1h**, *E/Z*-**5** ~9:1, **5**:**3** >95:5, 90-97% e.e.). By using **L7**/**L9**, some of the racemic products preparation ware achieved with 5 mol% cat. loading in a shorter reaction time. Hence, this HA also enables us to prepare an electron-deficient branched allylic carbon center from two abundant monoenes in polymer industry directly, which is valuable as it avoids complications in other routes like further 1,2-/1,4-addition in typical allylic substitutions.

Discussion

Although the above chemodivergent and regioselective cross-HA hypothesis aligns well with our observed result, a more detailed investigation was conducted since several conceivable mechanisms like oxidative cyclization[46,71-73] and β-CH insertion[9] are not impossible when using electron-deficient olefins as one of the substrates (Fig. 5, see SI for procedure). First, we inspected redox-active catalytic cycles involving (NHC)Ni(0) as alternate mechanism (Fig. 5a–b)[74-76]. Yet, experiments using the corresponding NHC/Ni(cod)$_2$ catalysts failed to deliver the desired products and instead resulted in nonselective consumption (Fig. 5c). This outcome is consistent with literature precedents where (NHC)Ni(0)-catalyzed conjugate additions of α-olefins to reactive α,β-unsaturated aldehydes require TESOTf as both a reactivity-directing substrate and carbonyl activator at 45 °C[77]. These comparisons indicate that our HA is unlikely to proceed via (NHC)Ni(0)-mediated pathways such as nickelacyclopentane intermediates (Fig. 5a, regioselective β-H eliminations)[71-73] or ligand-directed mechanistic shifts (Fig. 5b, change from redox-neutral insertion by **L4/L5**–Ni(II) for **3** to redox-active β-CH oxidative addition by **L7/L9**–Ni(0) for **5**)[9,24,78]. To rule out the redox-active pathways further, [**L4**-Ni(I)Cl]$_2$ was independently evaluated as a catalyst. Under otherwise identical conditions, no desired product was detected (Fig. 5d). Also, the catalytic performance remained unchanged even it was challenged by three different and highly competitive alkenes prone to radical paths (Fig. 5e, MHAT)[14,15,17,79].

Although we are unable to trap the hydrometallated species like the cross-HA of cyclopropenes by our catalyst[80], the use of d$_8$-**1a** reveals additional features of our reaction. In the catalytic synthesis of d$_n$-*E*-**5aa** by **L9**, over 33% of H (38%-40%) was incorporated at the Me position, and no deuterium was detected on carbon centers derived from **2a** by NMR (Fig. 5f). These data indicate that HM of d$_8$-**1a** is reversible with the **L9** catalyst and that the drop of D content at the methyl position partly supports a stepwise insertion mechanism (**1a**:**2a** = 1:1.5). In a separate homo-HA of **2a**, 39% conversion was observed and 28% **2a** was converted to h-h dimer within 10 mins, which may explain the D loss at the methyl position of the labeling study. In contrast, in a d$_n$-**3aa** preparation at a higher **L4** catalyst loading, a considerable amount of product bearing a CH_2 at the ester α-position and a gem-olefin at a low H incorporation was obtained (Fig. 5g). Hence, even though the **1a** HM is known to be facile and reversible[81], and despite d$_8$-**1a** was used in excess (d$_8$-**1a**:**2a** = 2:1), the HM of **2a** remains competitive and limits thorough Ni-H/D scrambling. Despite the Ni-H converts to Ni-D gradually, still no d$_n$-**2a** and no CD_2 at the ester α-position was detected at the end (CDH:CD_2 >95:5). These observations indicate that the hydrometallated **2a** rarely undergoes the backward reaction, possibly due to heteroatom stabilization as anticipated. Collectively, these results support that our cross-HA operates via a redox-neutral, divergent

synthetic approach complementing, rather than overlapping with, existing redox-active pathways with acrylate derivatives.

Next, we inspected whether the selectivity might arise from (NHC)Ni(II) directed regioselective isomerization[82,83], as **3** and **5** are a pair of isomers sharing the same carboskeleton (Fig. 6, see SI for procedure). However, neither interconversion among **3aa** and *E*-**5aa** (Fig. 6a-b, by switching between the two sets of NHC catalysts used in cross-HA) nor isomerization of the independently synthesized trisubstituted olefin *i*-**5aa** (Fig. 6c) occurred under catalytic conditions, even under prolonged reaction times and elevated temperatures. Indeed, only < 8% *Z*-**5aa** was obtained from heating a mixture of *E*-**5aa** and **2a** at 80 °C for 24 h, suggesting the catalyst suppresses further insertion and limits the HM of **5aa** to just favor Ni at its α-position (Fig. 6d). These findings demonstrate that, unlike other regiodivergent strategies by isomerization, no common olefin intermediate is involved.

Further mechanistic support was obtained from experiments with electron-deficient olefins of related structural features (Fig. 7). First, olefins bearing hemilabile coordinating groups that mimic the carbonyl and polarization direction of acrylates, like vinylsiloxanes **1q-r** were examined (deduced by ^{13}C NMR chemical shift of the two olefinic carbons, see SI for details). As anticipated, their corresponding cross-HA products **3** and **5** with styrene were formed likewise using **L4** and **L7** [Fig. 7a1) h-t and a2) t-h], and thus our strategy is not limited to olefins bearing C=O, and Si-OR is also usable. This reactivity is notable since the NHC catalyst using OTf as anion failed to provide the desired reactivity before.[84] Yet, a reduced **3**:**4** selectivity from >95:5 to 84:16 was noted (as a reflection of *l*/*b*-HM ratio) when replacing the $Si(OiPr)_3$ with a $SiMe_2Ph$ (Fig. 7a1, **1r** vs. **1s**, see SI for the reversed polarization[84]), approving the oxy-group and the olefin polarization direction assist the *l*-HM of electron-deficient olefin. Besides, the use of bulkier $vinylSi(OR)_3$ assists productivity (**3qa** vs. **3ra**; **5aq** vs. **5ar**), while the use of bulkier NHC was able to restore the high **3**:**4** selectivity in $vinylSiMe_2Ph$ (**L4** vs **L5**) but came at the cost of reduced reactivity (**3sa**), highlighting the need for optimal steric repulsion.

Interestingly, when preparing **5** with vinylsiloxane/silane substrates using **L7** catalyst, a detailed analysis revealed dissimilar predominant undesired substrate consumption pathways (Fig. 7a2). Nonselective styrene consumption was prevalent in vinylsilane cases (**1s**-**t**), while vinylsiloxanes (**1q**-**r**) homo-HA was the main side reaction, occurring at higher levels (up to 7% vs. <5%, and approximately 17% under forcing conditions without styrene). These findings elucidated the dual role of oxy-substituents in our divergent HA: while potentially compromising styrene's HM chemoselectivity, they facilitate chemo-

and regioselective CM through a deshielded β-C olefin site, just like acrylate. Therefore, the improved cross-/homo-selectivity observed with vinylsiloxane **1r** over **1q** is attributed partly to restored styrene HM via enhanced steric repulsion. Merely employing a flexible NHC structure without concerning the competition risks generating a mixture of styrene and vinylsiloxane homo-products. Besides, the marked productivity difference between vinyl$SiMe_2$Ph **1s** and vinylTMS **1t** (yield of **5as** >> **5at**) offers compelling evidence that the use of more deshielded β-C-position - rather than steric repulsion minimization with **L7** - as the key determinant of CM order (Fig. 7a2). Overall, the divergent HA streamlines the alkenyl and homoallyl silane synthetic routes starting from 1-silylcyclopropenes by B-H insertion[85] and from allylic silanes by anti-S_N2' allylic substitution[86], and this comparative study allowed us to underscore the key aspects for distinguishing the hemilabile coordination[87-91] and benzylic stabilization effectively by (NHC)Ni(II) catalysts.

Based on the above refined mechanistic insights, vinylBPin was chosen as the cross-HA partner with styrene, owing to its hemilabile oxy-coordination ability and steric bulk, despite its relatively low olefin polarization (Fig. 7b). As expected, the bulkier **L5** and the flexible **L7** catalysts delivered the target cross-HA products **3pa** and **5ap** as the major products at a slightly elevated temperature (Fig. 7b1, 69% yield, **3**:**4** > 95:5) and 7.5 mol% catalyst at r.t. (Fig. 7b3, 69-80% yield, **5**:**6** >95:5). Moreover, high e.e. of **5ap** is also achievable by using **L11** (88% e.e.)[92]. Notably, a double-branched t-t cross-HA product **6** was then observed by medium-sized NHCs (Fig. 7b2, **L3** and **L4**, up to 86% yield and 97% selectivity). These findings emphasize the dominant role of NHC steric effects in governing cross-HA product distribution, particularly with less polarized and weakly coordinating electron-deficient olefins. While chemodivergent HM of such combinations becomes more challenging, regiodivergent cross-CM can be modulated by strategic NHC ligand design - **L3**/**L4** favor the double-branched t-t product **6ap** over **4pa** , whereas **L7**/**L9** selectively yield the single-branched t-h product **5ap**.

Integrating our findings with relevant HA literature by NHC[12], we propose a (NHC)Ni(II)-directed, redox-neutral, insertion-based catalytic cross-HA cycle to account for the observations (Fig. 8). In the upper cycle (Fig. 8a), bulky NHC catalysts with optimal oxy-coordinating ability favor *l*-HM of olefin acceptor, followed by chemo- and regio-selective CM of styrene or α-olefin to deliver h-t product **3** (α-olefin shares similar polarization direction with styrene rather than acrylate). In the bottom cycle (Fig. 8b), flexible NHCs favor *b*-HM of styrene, after which chemoselective and regiodivergent CM yielding t-h product **5** or t-t product **6**. Minimizing steric repulsions among substituents on the C_2 symmetric chiral (*R*,*R*)-NHC and styrene directs the enantioselective *b*-HM. The open quadrant on the **L11** then allows the

chemo- and regio-selective CM of **2a** by lowering the concerned steric repulsion and matching the electronic demand in t-h isomer formation, yielding (*R*)-**5aa** (Fig. 9)[68,93]. Notably, unlike the steric effect directed styrene-α-olefin t-t cross-HA[51,81,94], the donor electronic effect is a crucial factor in controlling CM step in both cycles for high cross/homo-selectivity when pairing a suitable NHC (Fig. 10). It favors **3** and **5**, despite the homo-**h**-**t** of acrylate in (a) and homo-**t**-**h** of styrene in (b) are sterically comparable with the desired paths (see the dotted lines). In addition, this model also accounts for the differences among vinyl-silane and -siloxane behaviors (c-d), since they shared similar electronic characters with styrene and acrylate, respectively. Overall, this modular cross-HA system with twofold divergence (achieving chemoselective-HM and regioselective CM) efficiently delivers up to three distinct carboskeletons, each bearing a Bpin, SiR_3, or ester group alongside an alkenyl moiety.

In summary, this study unlocks one of the most straightforward strategies for highly chemodivergent and regioselective branched cross-HA of styrenes and electron-deficient olefins (controllable from 1 to another, out of 16 possible isomers). Our NHC catalyst pairs fundamentally enable the modular insertions through their trenchant responses to the hemilabile coordination, benzylic stabilization, and polarized olefin, facilitating branch-selective cross-HA that overcomes the intrinsic boundaries associated with strategies based on acid/base-directed organocatalytic paths (or from P/N-ligand dissociation), shared intermediate formation, isomerization, alkenyl halides, or steric repulsions alone. This work also represents a prominent expansion of olefin donor scope in (NHC)Ni(II)-directed cross-HA from α-olefins to acrylate derivatives, and it demonstrates that the donor polarization direction serves as a valuable tool beyond merely minimizing steric repulsion in CM step for high cross/homo-selectivity. Besides, the highly chemoselective acrylate *l*-HM strategy extends to h-t cross-HA with α-olefins, while the styrene *b*-HM strategy enables electron-deficient chiral allylic carbon center synthesis (up to 97% e.e.) without over additions. Overall, this system establishes a sustainable, modular platform for the divergent synthesis of conjugated olefins from abundant monoenes, and it underscores the need to develop NHC catalysts capable of discriminating subtle yet critical HM and CM determinants.

Methods

General procedure of the cross-HA. In a glove box, substrates **1** and **2** (indicated amount) were added to the in situ generated [(NHC)Ni(allyl)]NaBArF catalyst solution from [(NHC)Ni(allyl)Cl]/NaBArF/1-octene (0.025 mmol, Ni:NHC:NaBArF:1-octene = 1:1:1:2). The mixture was stirred at r.t. for 1-12 h (see SI for details). After work-up, the yield, structure, and selectivity of the desired product were determined by

NMR, HPLC, HRMS, and isolation. Full procedures and characterization data are provided in the Supplementary Information.

Data availability

All data supporting the findings of this study are available within the article and Supplementary Information. Data supporting the findings of this manuscript are also available from the corresponding author upon request.

References:

1 Jolly, P. W. & Wilke, G. in *Applied Homogeneous Catalysis with Organometallic Compounds* Vol. 2 (eds B. Cornils & W. A. Herrmann) 1024–1048 (VCH, 1996).

2 RajanBabu, T. V. in *Comprehensive Asymmetric Catalysis* Vol. 1 (eds E. N. Jacobsen, A. Pfaltz, & H. Yamamoto) 417–427 (Springer, 1999).

3 Francio, G., Faraone, F. & Leitner, W. Highly enantioselective nickel-catalyzed hydrovinylation with chiral phosphoramidite ligands. *J. Am. Chem. Soc.* **124**, 736–737 (2002). https://doi.org/10.1021/ja012099v

4 RajanBabu, T. V. Asymmetric hydrovinylation reaction. *Chem. Rev.* **103**, 2845–2860 (2003). https://doi.org/10.1021/cr020040g

5 Ho, C. Y., He, L. S. & Chan, C. W. NHC-NiH Reactions with Simple Olefins: Advances in Hydroalkenylation, Polymerization, and Ionic-Liquid Synthesis. *Synlett*, 1649–1653 (2011). https://doi.org/10.1055/s-0030-1260799

6 Hilt, G. Hydrovinylation Reactions - Atom-Economic Transformations with Steadily Increasing Synthetic Potential. *Eur. J. Org. Chem.*, 4441–4451 (2012). https://doi.org/10.1002/ejoc.201200212

7 Erver, F., Kuttner, J. R. & Hilt, G. Multidirectional Cobalt-Catalyzed Diels-Alder/1,4-Hydrovinylation Sequences. *J. Org. Chem.* **77**, 8375–8385 (2012). https://doi.org/10.1021/jo301028b

8 Hirano, M. & Komiya, S. Oxidative coupling reactions at ruthenium(0) and their applications to catalytic homo- and cross-dimerizations. *Coord. Chem. Rev.* **314**, 182–200 (2016). https://doi.org/10.1016/j.ccr.2015.07.008

9 Hirano, M. Recent Advances in the Catalytic Linear Cross-Dimerizations. *Acs Catal.* **9**, 1408–1430 (2019). https://doi.org/10.1021/acscatal.8b04676

10 Biswas, S. *et al.* A New Paradigm in Enantioselective Cobalt Catalysis: Cationic Cobalt(I) Catalysts for Heterodimerization, Cycloaddition, and Hydrofunctionalization Reactions of Olefins. *Acc. Chem. Res.* **54**, 4545–4564 (2021). https://doi.org/10.1021/acs.accounts.1c00573

11 Ho, C.-Y., Raja, D. in *Science of Synthesis* Vol. 2, Ch. 47.1.9, 307–389 (Georg Thieme Verlag KG, 2023). https://doi.org/10.1055/sos-SD-147-00289

12 Zhang, Z., Chen, Y., Gu, X. & Ho, C. Y. (NHC)Ni(II)-Directed Insertions and Higher Substituted Olefin Synthesis from Simple Olefins. *Acc. Chem. Res.* **56**, 1070–1086 (2023). https://doi.org/10.1021/acs.accounts.3c00035

13 Chatterjee, A. K., Choi, T. L., Sanders, D. P. & Grubbs, R. H. A general model for selectivity in olefin cross metathesis. *J. Am. Chem. Soc.* **125**, 11360–11370 (2003). https://doi.org/10.1021/ja0214882

14 Lo, J. C. L., Gui, J. H., Yabe, Y. K., Pan, C. M. & Baran, P. S. Functionalized olefin cross-coupling to construct carbon-carbon bonds. *Nature* **516**, 343–348 (2014). https://doi.org/10.1038/nature14006

15 Crossley, S. W. M., Obradors, C., Martinez, R. M. & Shenvi, R. A. Mn-, Fe-, and Co-Catalyzed Radical Hydrofunctionalizations of Olefins. *Chem. Rev.* **116**, 8912–9000 (2016). https://doi.org/10.1021/acs.chemrev.6b00334

16 Lo, J. C. *et al.* Fe-Catalyzed C-C Bond Construction from Olefins via Radicals. *J. Am. Chem. Soc.* **139**, 2484–2503 (2017). https://doi.org/10.1021/jacs.6b13155

17 Zhou, W., Dmitriev, I. A. & Melchiorre, P. Reductive Cross-Coupling of Olefins via a Radical Pathway. *J. Am. Chem. Soc.* **145**, 25098–25102 (2023). https://doi.org/10.1021/jacs.3c11285

18 Liu, P. *et al.* The first palladium-catalyzed 1,4-addition of terminal alkenes to acrylate esters. *Chem. Commun.* **49**, 5295–5297 (2013). https://doi.org/10.1039/c3cc41742e

19 Okamoto, K., Tamura, E. & Ohe, K. Acid-Catalyzed Direct Conjugate Alkenylation of α,β-Unsaturated Ketones. *Angew. Chem. Int. Ed.* **52**, 10639–10643 (2013). https://doi.org/10.1002/anie.201305188

20 Brookhart, M. & Saboetienne, S. Catalytic Tail-to-Tail Dimerization of Methyl Acrylate Using Rh(III) Catalysts. *J. Am. Chem. Soc.* **113**, 2777–2779 (1991). https://doi.org/10.1021/ja00007a076

21 Hirano, M., Arai, Y., Hamamura, Y., Komine, N. & Komiya, S. Stoichiometric and Catalytic Cross Dimerization between Conjugated Dienes and Conjugated Carbonyls by a Ruthenium(0) Complex: Straightforward Access to Unsaturated Carbonyl Compounds by an Oxidative Coupling Mechanism. *Organometallics* **31**, 4006–4019 (2012). https://doi.org/10.1021/om300234d

22 Timsina, Y. N., Sharma, R. K. & RajanBabu, T. V. Cobalt-catalysed asymmetric hydrovinylation of 1,3-dienes. *Chem. Sci.* **6**, 3994–4008 (2015). https://doi.org/10.1039/c5sc00929d

23 Jing, S. M., Balasanthiran, V., Pagar, V., Gallucci, J. C. & RajanBabu, T. V. Catalytic Enantioselective Hetero-dimerization of Acrylates and 1,3-Dienes. *J. Am. Chem. Soc.* **139**, 18034–18043 (2017). https://doi.org/10.1021/jacs.7b10055

24 Sun, X., Bai, X. Y., Li, A. Z. & Li, B. J. Iridium-Catalyzed Asymmetric Hydroalkenylation of Norbornene Derivatives. *Organometallics* **40**, 2182–2187 (2021). https://doi.org/10.1021/acs.organomet.0c00811

25 He, Y. L., Chen, J., Jiang, X. L. & Zhu, S. L. Enantioselective NiH-Catalyzed Reductive Hydrofunctionalization of Alkenes. *Chin. J. Chem.* **40**, 651–661 (2022). https://doi.org/10.1002/cjoc.202100763

26 Liu, C. F. *et al.* Synthesis of tri- and tetrasubstituted stereocentres by nickel-catalysed enantioselective olefin cross-couplings. *Nat. Catal.* **5**, 934–942 (2022). https://doi.org/10.1038/s41929-022-00854-8

27 Lee, B. C. *et al.* N-Heterocyclic carbenes as privileged ligands for nickel-catalysed alkene functionalisation. *Chem. Soc. Rev.* **52**, 2946–2991 (2023). https://doi.org/10.1039/d2cs00972b

28 Wang, J. W. *et al.* Nickel-Catalyzed α-selective Hydroalkylation of Vinylarenes. *Angew. Chem. Int. Ed.* **63** (2024). https://doi.org/10.1002/anie.202413074

29 Simlandy, A. K. *et al.* Enantioselective Hydroalkenylation and Hydroalkynylation of Alkenes Enabled by a Transient Directing Group: Catalyst Generality through Rigidification. *Angew. Chem. Int. Ed.* **62** (2023). https://doi.org/10.1002/anie.202304013

30 Vasseur, A., Bruffaerts, J. & Marek, I. Remote functionalization through alkene isomerization. *Nat. Chem.* **8**, 209–219 (2016). https://doi.org/10.1038/Nchem.2445

31 Sommer, H., Julia-Hernandez, F., Martin, R. & Marek, I. Walking Metals for Remote Functionalization. *Acs Cent. Sci.* **4**, 153–165 (2018). https://doi.org/10.1021/acscentsci.8b00005

32 Li, Y. Q., Wu, D., Cheng, H. G. & Yin, G. Y. Difunctionalization of Alkenes Involving Metal Migration. *Angew. Chem. Int. Ed.* **59**, 7990–8003 (2020). https://doi.org/10.1002/anie.201913382

33 Derosa, J., Apolinar, O., Kang, T., Tran, V. T. & Engle, K. M. Recent developments in nickel-catalyzed intermolecular dicarbofunctionalization of alkenes. *Chem. Sci.* **11**, 4287–4296 (2020). https://doi.org/10.1039/c9sc06006e

34 Wang, Y., He, Y. L. & Zhu, S. L. NiH-Catalyzed Functionalization of Remote and Proximal Olefins: New Reactions and Innovative Strategies. *Acc. Chem. Res.* (2022). https://doi.org/10.1021/acs.accounts.2c00628

35 Rodrigalvarez, J., Haut, F. L. & Martin, R. Regiodivergent C-H Functionalization via Ni-Catalyzed Chain-Walking Reactions. *J. Am. Chem. Soc. Au* **3**, 3270–3282 (2023). https://doi.org/10.1021/jacsau.3c00617

36 Rubel, C. Z. *et al.* Stereodivergent, Kinetically Controlled Isomerization of Terminal Alkenes via Nickel Catalysis. *Angew. Chem. Int. Ed.* **63** (2024). https://doi.org/10.1002/anie.202320081

37 Wang, H., Zhang, H. H., Martínez-Belmonte, M., Benet-Buchholz, J. & Martin, R. Regiodivergent Interrupted Ni-Catalyzed Chain-Walking of Unsaturated Alcohol Side-Chains via Traceless Activating Groups. *J. Am. Chem. Soc.* **147**, 28610–28616 (2025). https://doi.org/10.1021/jacs.5c09426

38 Arndt, M., Dindaroglu, M., Schmalz, H. G. & Hilt, G. Gaining Absolute Control of the Regiochemistry in the Cobalt-Catalyzed 1,4-Hydrovinylation Reaction. *Org. Lett.* **13**, 6236–6239 (2011). https://doi.org/10.1021/ol202696n

39 Ghosh, K. K. & RajanBabu, T. V. Ligand Effects in Carboxylic Ester- and Aldehyde-Assisted β-C-H Activation in Regiodivergent and Enantioselective Cycloisomerization-Hydroalkenylation and Cycloisomerization-Hydroarylation, and [2+2+2]-Cycloadditions of 1,6-Enynes. *J. Am. Chem. Soc.* (2024). https://doi.org/10.1021/jacs.4c06796

40 Beletskaya, I. P., Najera, C. & Yus, M. Chemodivergent reactions. *Chem. Soc. Rev.* **49**, 7101–7166 (2020). https://doi.org/10.1039/d0cs00125b

41 Najera, C., Beletskaya, I. P. & Yus, M. Metal-catalyzed regiodivergent organic reactions. *Chem. Soc. Rev.* **48**, 4515–4618 (2019). https://doi.org/10.1039/c8cs00872h

42 Sarkar, S., Ghosh, S., Kurandina, D., Noffel, Y. & Gevorgyan, V. Enhanced Excited-State Hydricity of Pd-H Allows for Unusual Head-to-Tail Hydroalkenylation of Alkenes. *J. Am. Chem. Soc.* **145**, 12224–12232 (2023). https://doi.org/10.1021/jacs.3c02410

43 Wang, H., Jie, X., Chong, Q. & Meng, F. Pathway-divergent coupling of 1,3-enynes with acrylates through cascade cobalt catalysis. *Nat. Commun.* **15**, 3427 (2024). https://doi.org/10.1038/s41467-024-47719-1

44 Zhou, Z. *et al.* Direct stereoselective C(sp(3))-H alkylation of saturated heterocycles using olefins. *Nat. Chem.* **17**, 344–355 (2025). https://doi.org/10.1038/s41557-025-01747-6

45 Li, J. S., Luo, Y. X., Cheo, H. W., Lan, Y. & Wu, J. Photoredox-Catalysis-Modulated, Nickel-Catalyzed Divergent Difunctionalization of Ethylene. *Chem* **5**, 192–203 (2019). https://doi.org/10.1016/j.chempr.2018.10.006

46 Singh, D. & RajanBabu, T. V. Chemodivergent, Regio- and Enantioselective Cycloaddition Reactions between 1,3-Dienes and Alkynes. *Angew. Chem. Int. Ed.* **62**, e202216000 (2023). https://doi.org/10.1002/anie.202216000

47 Xu, S. *et al.* Stereoselective and site-divergent synthesis of C-glycosides. *Nat. Chem.* **16**, 2054–2065 (2024). https://doi.org/10.1038/s41557-024-01629-3

48 Wu, F. L., Wang, H. K., Wu, Z. W., Liu, Y. B. & Feng, X. M. Solvent-Controlled Enantioselective Allylic C-H Alkylation of 2,5-Dihydrofuran via Synergistic Palladium/Nickel Catalysis. *J. Am. Chem. Soc.* **147**, 16237–16247 (2025). https://doi.org/10.1021/jacs.5c01228

49 von Muenchow, T. *et al.* Enantioselective C-H annulations enabled by either nickel- or cobalt-electrocatalysed C-H activation for catalyst-controlled chemodivergence. *Nat. Catal.* **8**, 257–269 (2025). https://doi.org/10.1038/s41929-025-01306-9

50 Liu, J. M. *et al.* Chemodivergent, enantio- and regioselective couplings of alkynes, aldehydes and silanes enabled by nickel/N-heterocyclic carbene catalysis. *Sci. Bull. (Beijing)* **70**, 674–682 (2025). https://doi.org/10.1016/j.scib.2024.12.023

51 Ho, C. Y. & He, L. S. Catalytic Intermolecular Tail-to-Tail Hydroalkenylation of Styrenes with alpha Olefins: Regioselective Migratory Insertion Controlled by a Nickel/N-Heterocyclic Carbene. *Angew. Chem. Int. Ed.* **49**, 9182–9186 (2010). https://doi.org/10.1002/anie.201001849

52 DiRenzo, G. M., White, P. S. & Brookhart, M. Mechanistic studies of catalytic olefin dimerization reactions using electrophilic eta(3)-allyl-palladium(II) complexes. *J. Am. Chem. Soc.* **118**, 6225–6234 (1996). https://doi.org/10.1021/ja9602354

53 Gomez-Suarez, A., Nelson, D. J. & Nolan, S. P. Quantifying and understanding the steric properties of N-heterocyclic carbenes. *Chem. Commun.* **53**, 2650–2660 (2017). https://doi.org/10.1039/c7cc00255f

54 Clavier, H. & Nolan, S. P. Percent buried volume for phosphine and N-heterocyclic carbene ligands: steric properties in organometallic chemistry. *Chem. Commun.* **46**, 841–861 (2010). https://doi.org/10.1039/b922984a

55 Gusev, D. G. Electronic and Steric Parameters of 76 N-Heterocyclic Carbenes in Ni(CO)3(NHC). *Organometallics* **28**, 6458–6461 (2009). https://doi.org/10.1021/om900654g

56 Huynh, H. V. Electronic Properties of N-Heterocyclic Carbenes and Their Experimental Determination. *Chem. Rev.* **118**, 9457–9492 (2018). https://doi.org/10.1021/acs.chemrev.8b00067

57 Fliedel, C., Labande, A., Manoury, E. & Poli, R. Chiral N-heterocyclic carbene ligands with additional chelating group(s) applied to homogeneous metal-mediated asymmetric catalysis. *Coord. Chem. Rev.* **394**, 65–103 (2019). https://doi.org/10.1016/j.ccr.2019.05.003

58 Jayaraj, A., Raveedran, A. V., Latha, A. T., Priyadarshini, D. & Swamy, P. C. A. Coordination Versatility of NHC-metal Topologies in Asymmetric Catalysis: Synthetic Insights and Recent Trends. *Coord. Chem. Rev.* **478** (2023). https://doi.org/10.1016/j.ccr.2022.214922

59 Zhou, T. L., Utecht-Jarzynska, G. & Szostak, M. Ring-expanded N-heterocyclic carbene (reNHC) complexes: Applications in transition metal catalysis. *Coord. Chem. Rev.* **512** (2024). https://doi.org/10.1016/j.ccr.2024.215867

60 Koser, L., Lechner, V. M. & Bach, T. Biomimetic Total Synthesis of Enterocin. *Angew. Chem. Int. Ed.* **60**, 20269–20273 (2021). https://doi.org/10.1002/anie.202108157

61 Fukuda, M., Ohkoshi, E., Makino, M. & Fujimoto, Y. Studies on the constituents of the leaves of (Asteraceae) and their cytotoxic activity. *Chem. Pharm. Bull.* **54**, 1465–1468 (2006). https://doi.org/10.1248/cpb.54.1465

62 Goncalves-Contal, S., Gremaud, L. & Alexakis, A. Enantioselective Copper-Catalyzed Conjugate Addition of Trimethylaluminum to β,γ-Unsaturated α-Ketoamides: Efficient Access to γ-Methyl-Substituted Carbonyl Compounds. *Angew. Chem. Int. Ed.* **52**, 12701–12704 (2013). https://doi.org/10.1002/anie.201306541

63 Jampilek, J. Heterocycles in Medicinal Chemistry. *Molecules* **24** (2019). **https://doi.org/10.3390/molecules24213839**

64 Heravi, M. M. & Zadsirjan, V. Prescribed drugs containing nitrogen heterocycles: an overview. *Rsc Adv.* **10**, 44247–44311 (2020). https://doi.org/10.1039/d0ra09198g

65 Kerru, N., Gummidi, L., Maddila, S., Gangu, K. K. & Jonnalagadda, S. B. A Review on Recent Advances in Nitrogen-Containing Molecules and Their Biological Applications. *Molecules* **25** (2020). **https://doi.org/10.3390/molecules25081909**

66 Stojalnikova, V., Webster, S. J., Liu, K. & Fletcher, S. P. Chelation enables selectivity control in enantioconvergent Suzuki-Miyaura cross-couplings on acyclic allylic systems. *Nat. Chem.* **16** (2024). https://doi.org/10.1038/s41557-023-01430-8

67 Johnson, W. S. *et al.* A Simple Stereoselective Version of Claisen Rearrangement Leading to Trans-Trisubstituted Olefinic Bonds . Synthesis of Squalene. *J. Am. Chem. Soc.* **92**, 741–+ (1970). https://doi.org/10.1021/ja00706a074

68 López, F., van Zijl, A. W., Minnaard, A. J. & Feringa, B. L. Highly enantioselective Cu-catalysed allylic substitutions with Grignard reagents. *Chem. Commun.* 409–411 (2006). https://doi.org/10.1039/b513887f

69 Aloia, A., Casiello, M., Nacci, A. & Monopoli, A. Selective Palladium(II) ‐ Catalyzed Dimerization of Styrenes and Acrylates in Molten Tetrabutylammonium Acetate as an Ionic Liquid. *Eur. J. Org. Chem.* **27** (2024). https://doi.org/10.1002/ejoc.202400111

70 We found that vinylarene 1f-h are not reactive donors at here. It is possibly because of their much lower olefin polarization than the styrene derivatives (see the rationale later).

71 Ogoshi, S., Oka, M. & Kurosawa, H. Direct observation of oxidative Cyclization of eta(2)-alkene and eta(2)-aldehyde on Ni(0) center. Significant acceleration by addition of Me3SiOTf. *J. Am. Chem. Soc.* **126**, 11802–11803 (2004). https://doi.org/10.1021/ja0460716

72 Ogoshi, S., Haba, T. & Ohashi, M. Nickel-Catalyzed Direct Conjugate Addition of Simple Alkenes to Enones. *J. Am. Chem. Soc.* **131**, 10350 (2009). https://doi.org/10.1021/ja903510u

73 Ohashi, M., Taniguchi, T. & Ogoshi, S. Nickel-catalyzed formation of cyclopentenone derivatives via the unique cycloaddition of alpha,beta-unsaturated phenyl esters with alkynes. *J. Am. Chem. Soc.* **133**, 14900–14903 (2011). https://doi.org/10.1021/ja2059999

74 Ho, C. Y. & Jamison, T. F. Highly selective coupling of alkenes and aldehydes catalyzed by [Ni(NHC){P(OPh)(3)}]: Synergy between a strong sigma donor and a strong pi acceptor. *Angew. Chem. Int. Ed.* **46**, 782–785 (2007). https://doi.org/10.1002/anie.200603907

75 Ng, S.-S., Ho, C.-Y. & Jamison, T. F. Nickel-catalyzed coupling of alkenes, aldehydes, and silyl triflates. *J. Am. Chem. Soc.* **128**, 11513–11528 (2006). https://doi.org/10.1021/ja062866w

76 Ho, C. Y., Ng, S. S. & Jamison, T. F. Nickel-catalyzed, carbonyl-ene-type reactions: Selective for alpha olefins and more efficient with electron-rich aldehydes. *J. Am. Chem. Soc.* **128**, 5362–5363 (2006). https://doi.org/10.1021/ja061471+

77 Ho, C. Y., Ohmiya, H. & Jamison, T. F. alpha-Olefins as alkenylmetal equivalents in catalytic conjugate addition reactions. *Angew. Chem. Int. Ed.* **47**, 1893–1895 (2008). https://doi.org/10.1002/anie.200705163

78 Hiroi, Y., Komine, N., Komiya, S. & Hirano, M. Asymmetric Cross-Dimerization between Methyl Methacrylate and Substituted Alkene by Ru(0),ÄìBicyclononadiene Complex. *Org. Lett.* **15**, 2486–2489 (2013). https://doi.org/10.1021/ol400963d

79 Herbort, J. H., Bednar, T. N., Chen, A. D., RajanBabu, T. V. & Nagib, D. A. gamma C-H Functionalization of Amines via Triple H-Atom Transfer of a Vinyl Sulfonyl Radical Chaperone. *J. Am. Chem. Soc.* **144**, 13366–13373 (2022). https://doi.org/10.1021/jacs.2c05266

80 Huang, J. Q. & Ho, C. Y. [(NHC)(NiH)]-Catalyzed Cross-Hydroalkenylation of Cyclopropenes with Alkynes: Cyclopentadiene Synthesis by [(NHC)Ni-II]-Assisted C-C Rearrangement. *Angew. Chem. Int. Ed.* **58**, 5702–5706 (2019). https://doi.org/10.1002/anie.201901255

81 Hong, X. *et al.* Computational Exploration of Mechanism and Selectivities of (NHC)Nickel(II)hydride-Catalyzed Hydroalkenylations of Styrene with alpha-Olefins. *Acs Catal.* **5**, 5545–5555 (2015). https://doi.org/10.1021/acscatal.5b01075

82 Kondoh, A., Odaira, K. & Terada, M. Ring Expansion of Epoxides under Bronsted Base Catalysis: Formal [3+2] Cycloaddition of β,γ-Epoxy Esters with Imines Providing 2,4,5-Trisubstituted 1,3-Oxazolidines. *Angew. Chem. Int. Ed.* **54**, 11240–11244 (2015). https://doi.org/10.1002/anie.201505893

83 Guha, S. K. *et al.* "Syn-Effect" In the conversion of (*E*)-α,β-unsaturated esters into the corresponding β,γ-unsaturated esters and aldehydes into silyl enol ethers. *Bull. Chem. Soc. Jpn.* **77**, 2147–2157 (2004). https://doi.org/10.1246/bcsj.77.2147

84 Ho, C. Y. & He, L. S. Shuffle off the classic beta-Si elimination by Ni-NHC cooperation: implication for C-C forming reactions involving Ni-alkyl-beta-silanes. *Chem. Commun.* **48**, 1481–1483 (2012). https://doi.org/10.1039/c1cc14593b

85 Huang, M. Y., Zhao, Y. T., Zhang, C. D. & Zhu, S. F. Highly Regio-, Stereo-, and Enantioselective Copper-Catalyzed B-H Bond Insertion of alpha-Silylcarbenes: Efficient Access to Chiral Allylic gem-Silylboranes. *Angew. Chem. Int. Ed.* **61**, e202203343 (2022). https://doi.org/10.1002/anie.202203343

86 Perrone, S. & Knochel, P. Highly diastereoselective preparation of (E)-alkenylsilanes bearing an alpha-chiral center. *Org. Lett.* **9**, 1041–1044 (2007). https://doi.org/10.1021/ol063097o

87 Strauss, S. H. The Search for Larger and More Weakly Coordinating Anions. *Chem. Rev.* **93**, 927–942 (1993). https://doi.org/10.1021/cr00019a005

88 Nandi, M., Jin, J. & RajanBabu, T. V. Synergistic Effects of Hemilabile Coordination and Counterions in Homogeneous Catalysis: New Tunable Ligands for Hydrovinylation Reactions. *J. Am. Chem. Soc.* **121**, 9899–9900 (1999). https://doi.org/10.1021/ja992493h

89 Holscher, M., Francio, G. & Leitner, W. Origin of enantioselectivity in asymmetric hydrovinylations catalyzed by phosphoramidite nickel catalysts: An experimentally supported density functional study. *Organometallics* **23**, 5606–5617 (2004). https://doi.org/10.1021/om040107l

90 RajanBabu, T. V. *et al.* Heterodimerization of olefins. 1. Hydrovinylation reactions of olefins that are amenable to asymmetric catalysis. *J. Org. Chem.* **68**, 8431–8446 (2003). https://doi.org/10.1021/jo035171b

91 Ho, C. Y. & He, L. Medium-Sized Heterocycle Synthesis by the Use of Synergistic Effects of Ni-NHC and gamma-Coordination in Cycloisomerization. *J. Org. Chem.* **79**, 11873–11884 (2014). https://doi.org/10.1021/jo5008477

92 It should be noted that **L11** is also capable of synthesizing product **5** from the vinylsiloxanes and styrene. Unfortunately, we are unable to determine the corresponding product e.e. accurately in our hands so far.

93 van Zijl, A. W., Szymanski, W., López, F., Minnaard, A. J. & Feringa, B. L. Catalytic enantioselective synthesis of vicinal dialkyl arrays. *J. Org. Chem.* **73**, 6994–7002 (2008). https://doi.org/10.1021/jo8010649

94 Ho, C. Y., Chan, C. W. & He, L. S. Catalytic Asymmetric Hydroalkenylation of Vinylarenes: Electronic Effects of Substrates and Chiral N-Heterocyclic Carbene Ligands. *Angew. Chem. Int. Ed.* **54**, 4512–4516 (2015). https://doi.org/10.1002/anie.201411882

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Author contributions

X.G. and J.-J. K performed experimental studies and analysis. J.-H. D conducted part of the racemic 5 preparation. J.-Z. S helped the substrates preparation and products purification. Z.-F. Z conducted synthesis of chiral ligands. M.-K. W. and C.-Y. H. collaborated the project and supervised the work.

Competing interests

The authors declare no competing interests.

Figure legends

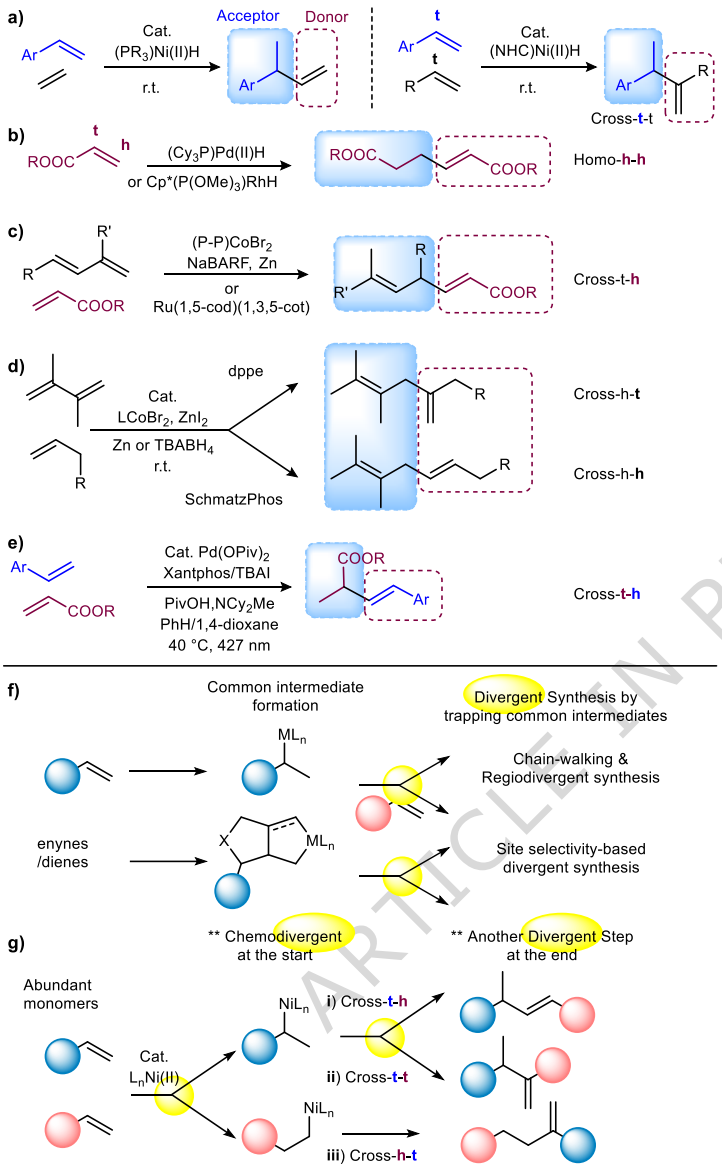


Fig. 1. Catalytic cross-hydroalkenylation: from regio- and chemo-selective to divergent. a) Hydrovinylation and hydroalkenylation of styrene. **b)** Homo-hydroalkenylation of methyl acrylate. **c)** Heterodimerization of methyl acrylate & 1,3-diene (oxidative cyclization). **d)** Regio-divergent cross-dimerization (trapping the same intermediate). **e)** Pd-catalyzed hydroalkenylation of acrylate and styrene. **f)** Conventional divergent alkenylation. **g)** This work: chemodivergent and regioselective cross-hydroalkenylation.

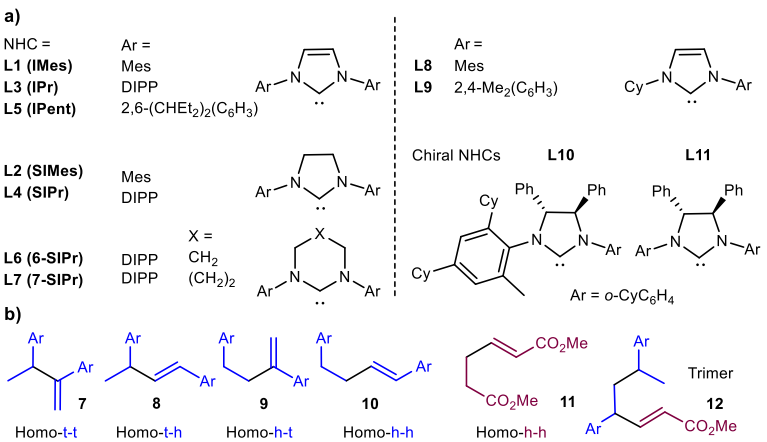
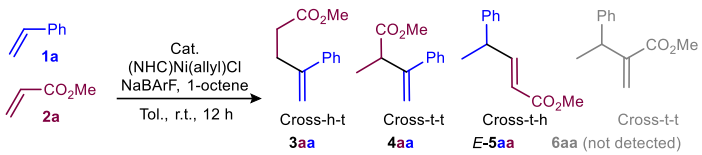


Fig. 2. Structures of NHCs, homo-hydroalkenylation and trimerization products in this work. Mes = mesityl. DIPP = diisopropylphenyl. **a)** Structures of NHCs. **b)** Structures of homo-products.



NHC[b]	Cross-HA Yield (%)	3:4	5:(3+4)	Cross-HA:Homo-1a/ Cross-HA:Homo-2a
a)				
L1 (36.5)	23	55:45	/	66:33/>95:5
L2 (37.1)	36	69:31	/	50:50/90:10
L3 (45.5)	67	78:22	/	51:49/>95:5
L4 (47.4)	83	77:23	/	53:47/>95:5
L5 (49.0)	31	>95:5	/	88:12/>95:5
	36[c]	92:8	/	88:12/>95:5
	53[d]	>95:5	/	84:16/>95:5
	71[cd]	94:6	/	73:27/>95:5
b)				
L6 (50.9)	58	/	>95:5	>95:5/>95:5
L7 (52.7)	50	/	>95:5	>95:5/>95:5
L8 (~34.5)	36	/	>95:5	60:40/>95:5[g]
L9 (~36.5-27.5)	58	/	>95:5	>95:5/94:6
	88[e]	/	>95:5	>95:5/94:6
c)				
L10 n.a.	17[e]	/	>95:5	>95:5/>95:5
L11 n.a.	95[ef]	/	>95:5	>95:5/83:17

Fig. 3. Screening of NHC for chemodivergent cross-hydroalkenylation of 1a and 2a.[a] n.a. = not available. **a)** Bulky and symmetric NHCs. **b)** sterically adaptive cores or less-substituted NHCs. **c)** Chiral NHCs. **a** The reactions were performed by following the procedure: **1a** and **2a** (2: 1, 0.25 mmol) were added to 10 mol% [(NHC)Ni(allyl)Cl]/NaBArF (NaBArF = Sodium tetrakis[3,5-bis(trifluoromethyl)phenyl]borate) catalyst in 2 mL toluene with 1-octene (20 mol%) and stirred at r.t. for 12 h. Selectivity and yield were determined by crude ^{1}H NMR using CH_3NO_2 as standard. The desired cross-HA product structures, **3aa**, **4aa** and **5aa**, were confirmed by isolation, and no **6aa** was observed. The major homo-HA of **1a** and **2a** were determined as **7aa**, **8aa**, and **11aa**, and no **9aa** and **10aa** were observed (see Fig. 2 for structures). *E*/*Z*-**5aa** ~ 91:9. The substrate nonselective consumption was presumably caused by oligomerization. **b** Value in parenthesis is %V_{bur} for (NHC)AuCl at length of 2.00 Å. **L8** and **L9** are estimated by closely related NHCs. **L8** by a N-pinanyl substituted NHC; **L9** by the data from ICy/IMes. **c** 50 °C. **d** **1a**: **2a** = 3: 1. **e** 2.5 mol% of cat., **1a**:**2a** = 1:1.5, 1 h. **f** 97% e.e., determined by chiral HPLC ((*R*)-product, OD-H column, see SI for details). **g** < 5% of trimer **12aaa** was noted by NMR in this screening.

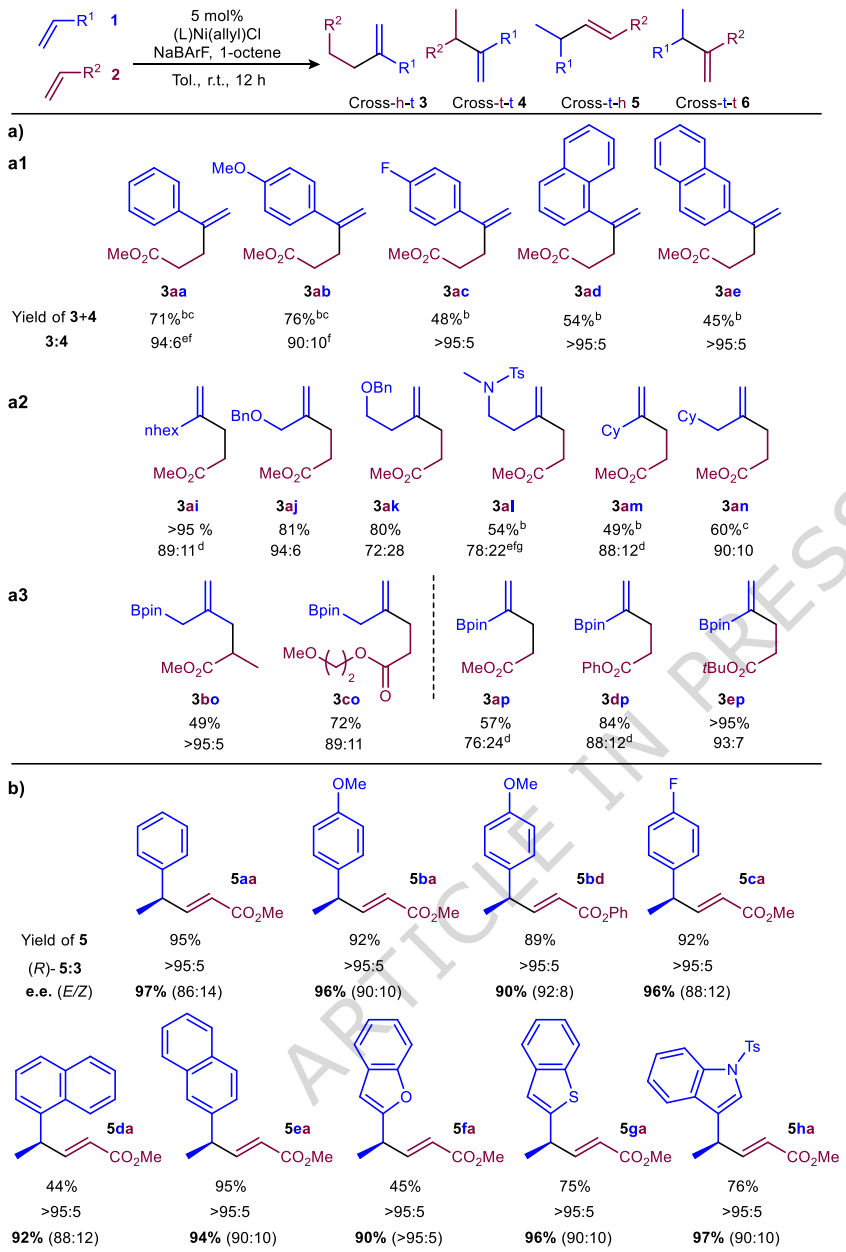


Fig. 4. Scope and applications of the chemo- and regio-selective hydrometallation.[a] **a)** Acrylate as acceptor; L = **L4**; **1**:**2a** = 2:1; (**3**+**4**):**5** > 95:5; cross-HA:homo-**2a** >95:5. **a1** R^1 = aryls ; **2a** R^2 = COOMe. **a2** R^1 = alkyls ; **2a** R^2 = COOMe. **a3** Bpin substituted **1o** & **1p**. **b)** Styrene as acceptor; L = **L11**[b]; **1**:**2** = 1:1.5, **3** & **4** & **6** < 5%; cross-HA:homo-**1** >95:5. **a** The reactions were performed by following the procedure: Indicated substrate ratio was added to 5 mol% [(NHC)Ni(allyl)Cl]/NaBArF in 2 mL toluene with 1-octene (20 mol%) and stirred at r.t. for 12 h. Selectivity and yield were determined by crude ^{1}H NMR using CH_3NO_2 as standard like Fig. 3, the desired cross-HA product structures were confirmed by isolation, the amount of minor product **4** was estimated by the characteristic ^{1}H NMR peaks of **4aa** and related examples reported in the literature (See SI). The e.e. of *E*-**5** was determined by chiral HPLC and (*R*)-configuration were assigned by comparison with the optical rotation of **3aa** reported by other methods. **b** 10 mol% catalyst.**c** NHC = **L5**. **d**,**e** 35 °C and 50 °C. **f** **1**:**2a** = 3:1. **g** 0.125 mmol substrate.

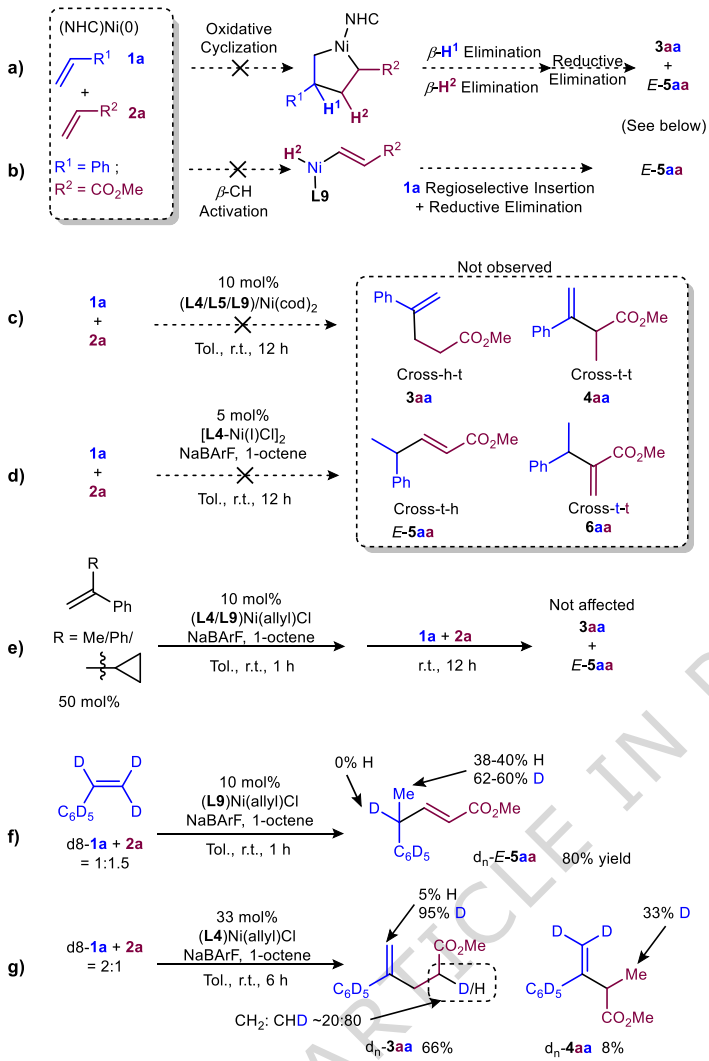


Fig. 5. Other underdeveloped pathways and mechanistic studies for the catalytic cross-HA. a) Oxidative cyclization pathway. **b)** β-CH activation pathway. **c)** Attempts of cross-HA by using Ni(0) catalyst. **d)** Attempt of cross-HA by using Ni(I) catalyst. **e)** Attempts of cross-HA with 1-substituted styrene as additives. **f)** D-labeled experiment by using **L9**. **g)** D-labeled experiment by using **L4**.

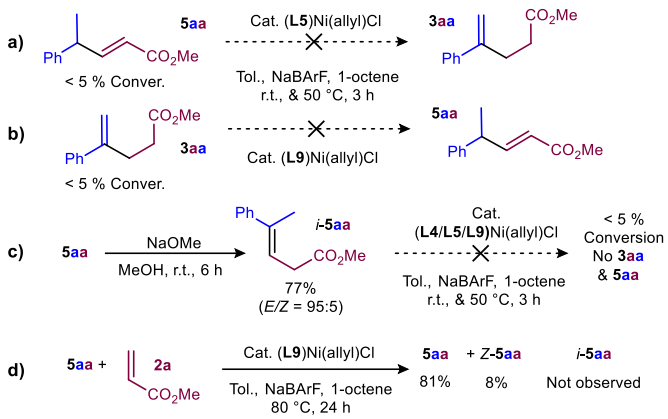


Fig. 6. Control experiments for the selective olefin formation. a) Isomerization attempt of **5aa** to **3aa** by using **L5**. **b)** Isomerization attempt of **3aa** to **5aa** by using **L9**. **c)** Preparation of *i*-**5aa** and the isomerization attempts of *i*-**5aa**. **d)** Isomerization attempt of **5aa** under prolonged reaction times and elevated temperature by using **L9**.

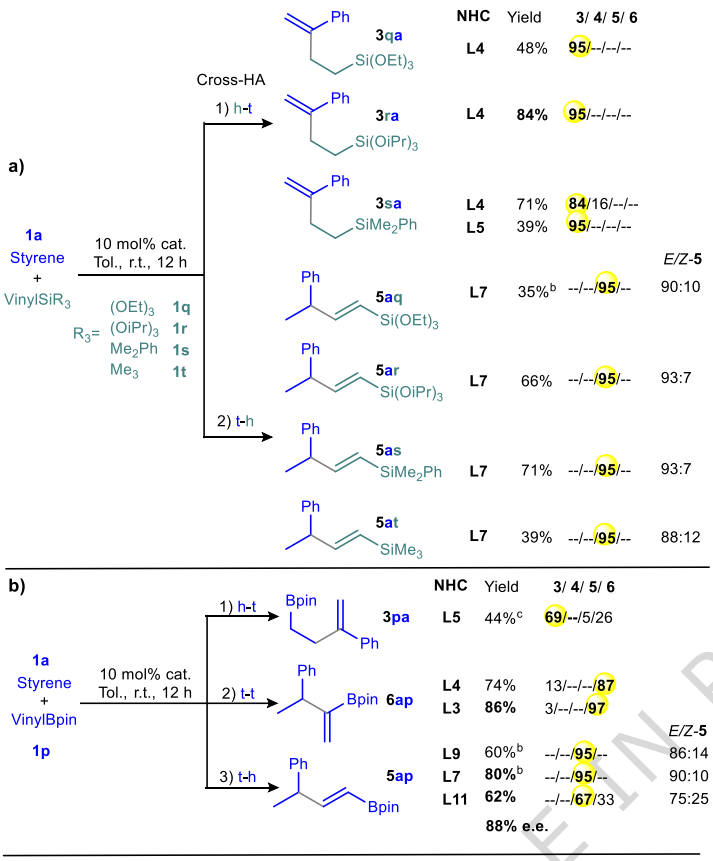


Fig. 7. Vinylsiloxanes and vinylBpin as acrylate equivalents in chemodivergent cross-HA.[a] **a)** Vinylsiloxanes and vinylsilanes as acrylate equivalents. **b)** VinylBpin as acrylate equivalents. **a** The reactions were performed by following the procedure: Indicated substrate ratio was added to 10 mol% [(NHC)Ni(allyl)Cl]/NaBArF in 2 mL toluene with 1-octene (20 mol%) and stirred at r.t. for 12 h. Selectivity and yield were determined by crude ^{1}H NMR using CH_3NO_2 as standard like Fig. 3, the desired cross-HA product structures were confirmed by isolation, the amount of minor product **4** was estimated by the characteristic ^{1}H NMR peaks of **4aa** and related examples reported in the literature (See SI). The e.e. of product *E*-**5** was determined by chiral HPLC and (*R*)-configuration were assigned by comparison with the optical rotation of **3aa** reported in the literature. **b** 7.5 mol% catalyst. **c** 35 °C.

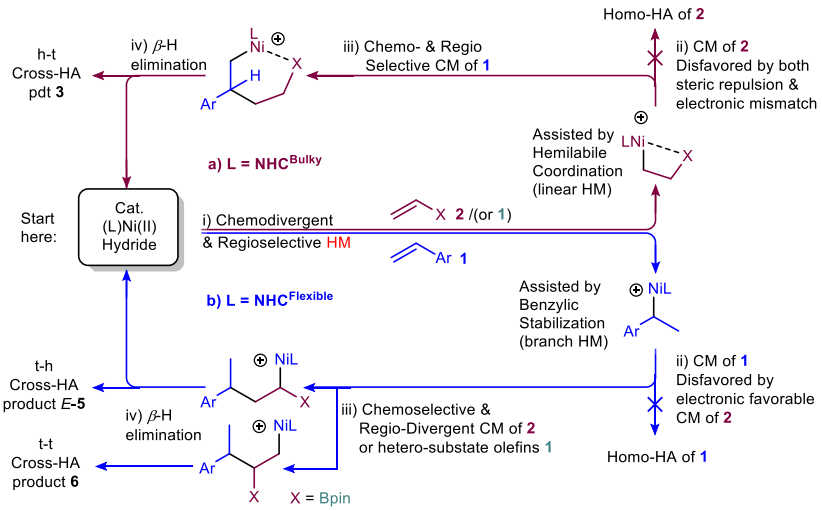


Fig. 8. Proposed mechanism for the (NHC)Ni(II) directed divergent cross-HA. HM = hydrometallation. CM = carbometallation. **a)** Bulky NHC assisted by hemilabile coordination. **b)** Flexible NHC assisted by benzylic stabilization.

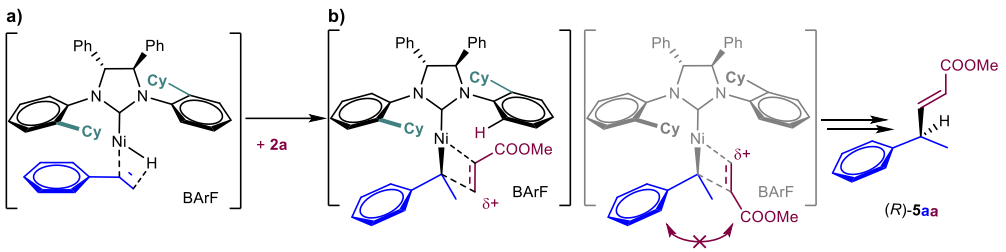


Fig. 9. Proposed model for the enantioselective preparation of (*R*)-5aa by L11. a) Minimizing undesired steric repulsion among styrene & (*R*,*R*)-C_2 NHC *o*-Cy. **b)** Open quadrant assisted regioselective CM of MA.

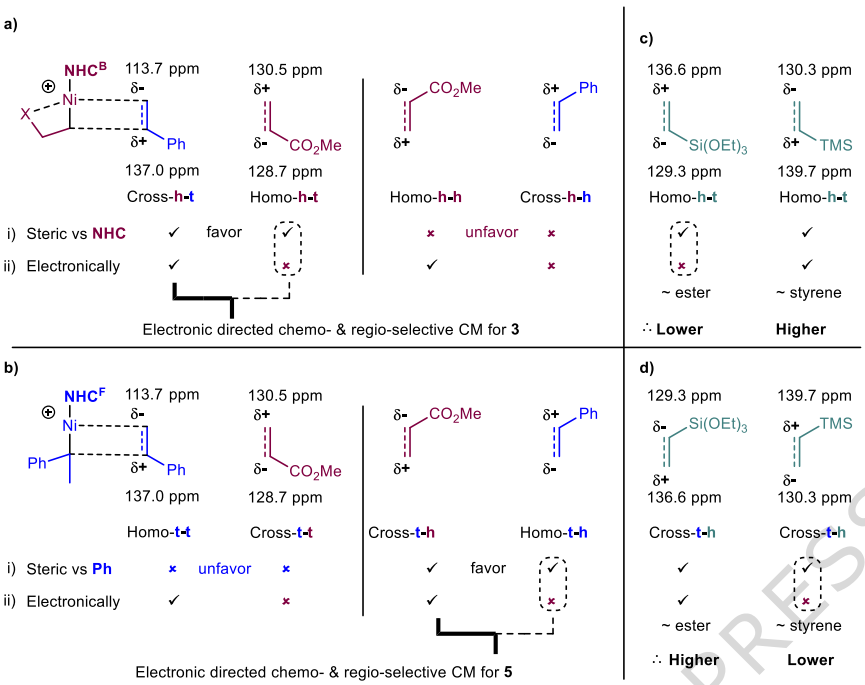


Fig. 10. Proposed models for the donor polarization effect on CM selectivity. a) CM step in Fig. 8a for **3**. **b)** CM step in Fig. 8b for **5**. **c)** rationale for different homo-**h**-**t** levels. **d)** rationale for different cross-**t**-**h** levels.

The authors present a straightforward chemodivergent and regioselective cross-hydroalkenylation of acrylates and vinylarenes, enabling intermolecular access to distinct conjugated olefin isomers that were previously inaccessible from those abundant substrate classes directly.

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