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# Mixing and matching *N,N*- and *N,O*-chelates in anionic Mg(I) compounds: synthesis and reactivity with $\text{RN}=\text{C}=\text{NR}$ and $\text{CO}^\dagger$

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**Reduction of  $[\text{Mg}(\text{NON})_2]$  ( $[\text{NON}]^{2-} = [\text{O}(\text{SiMe}_2\text{NDipp})_2]^{2-}$ , Dipp = 2, 6-*i*-Pr<sub>2</sub>C<sub>6</sub>H<sub>3</sub>) affords Mg(I) species containing NON- and NNO-ligands ( $[\text{NNO}]^{2-} = [\text{N}(\text{Dipp})\text{SiMe}_2\text{N}(\text{Dipp})\text{SiMe}_2\text{O}]^{2-}$ ). The products of reactions with  $\text{iPrN}=\text{C}=\text{NiPr}$  and CO are consistent with the presence of reducing Mg(I) centres. Extraction with THF affords  $[\text{K}(\text{THF})_2]_2[\text{NNO}\text{Mg}-\text{Mg}(\text{NNO})]$  with a structurally characterised Mg–Mg bond that was examined using density functional theory.**

Since the initial report of (BDI)Mg–Mg(BDI) in 2007 (I, Fig. 1; BDI =  $[\text{HC}\{\text{C}(\text{Me})\text{NDipp}\}_2]^-$ ),<sup>1</sup> Mg(I) reagents have demonstrated their capacity to act as soluble, electron precise reducing agents.<sup>2</sup> The discovery of these compounds has undoubtedly fuelled the recent development and application of low valent group 2 (alkaline earth, Ae) metal complexes.<sup>3</sup> Indeed, over 35 examples of neutral Mg(I) species (L)Mg–Mg(L) (L = monoanionic ligand) have now been structurally characterised. In contrast, examples in which the low valent magnesium centres are present in an anionic  $[(\text{L}')\text{Mg}-\text{Mg}(\text{L}')]^{2-}$  unit (L' = dianionic ligand) are a recent addition to this important family of compounds (Fig. 1).

The first anionic Mg(I) compounds II were synthesised in a one-pot reaction of the neutral diimine or diamine with MgCl<sub>2</sub> in the presence of excess potassium.<sup>4</sup> The products have a coplanar  $[(\text{L}')\text{Mg}-\text{Mg}(\text{L}')]^{2-}$  unit with THF-solvated potassium cations above and below the MgN<sub>2</sub>C<sub>2</sub> metallacycles. In 2021,

Hill and co-workers isolated the dimeric Na/Mg complex III by reducing the neutral diamido magnesium precursor with 5% Na/NaCl.<sup>5</sup> The structure showed non-solvated sodium cations with Na··π(arene) interactions to ligand substituents. The  $[(\text{L}')\text{Mg}-\text{Mg}(\text{L}')]^{2-}$  unit is twisted, with a long Mg–Mg bond. The most recent addition to this family IV, derives from the steric modulation of a rigid  $[\text{xanth-EtNON}^{\text{Ar}}]^{2-}$  backbone ( $[\text{xanth-EtNON}^{\text{Ar}}]^{2-} = 4,5\text{-Ar}_2\text{-2,7-Et}_2\text{-9,9-Me}_2\text{-xanthene}$ ). Previous work had shown that when Ar = 2,4,6-Cy<sub>3</sub>C<sub>6</sub>H<sub>2</sub>, the dinitrogen complex  $[\text{K}\{\text{Mg}(\text{xanth-EtNON}^{\text{Ar}})\}]_2(\mu\text{-N}_2)$  was isolated,<sup>6</sup> presumed to be due to the ligand bulk preventing Mg–Mg bond formation and the resulting Mg(I) radicals reducing

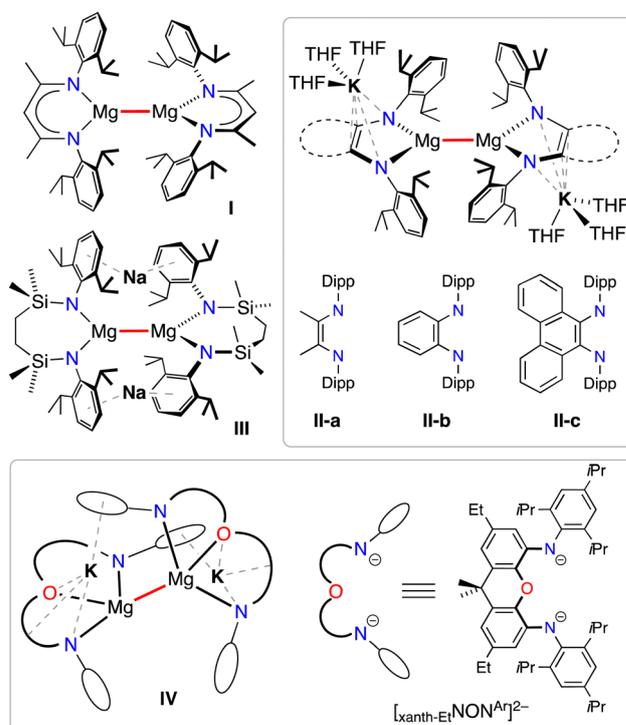


Fig. 1 Examples of neutral (I) and anionic (II, III and IV) Mg(I) compounds.

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<sup>†</sup> Electronic supplementary information (ESI) available: Experimental details and characterization data; full details of computational experiments. CCDC 2357068 (1), 2357069 (2), 2357070 (3-Et<sub>2</sub>O) and 2357071 (4-THF). For ESI and crystallographic data in CIF or other electronic format see DOI: <https://doi.org/10.1039/d4cc02594f>


N<sub>2</sub>. Reducing the size of the Ar substituents to 2,4,6-*i*Pr<sub>3</sub>C<sub>6</sub>H<sub>2</sub> allowed Mg–Mg bond formation in **IV**.<sup>7</sup> The solid-state structure of **IV** adopts a folded structure with the potassium atoms coordinated *via* η<sup>4</sup>-OCN<sub>2</sub> and η<sup>6</sup>-aryl interactions to the ligands.

The reactivity of anionic Mg(i) compounds with a range of small molecules (H<sub>2</sub>, CO, N<sub>2</sub>O, THF),<sup>5,7,8</sup> and organic functional groups (alkynes, nitriles, carbodiimides, ketones, polyaromatic compounds)<sup>9</sup> has been explored, confirming the reductive capability of these species. We report herein the synthesis of a magnesium compound supported by the NON-ligand [(NON)]<sup>2-</sup> = [O(SiMe<sub>2</sub>NDipp)<sub>2</sub>]<sup>2-</sup>, its reduction to Mg(i) and the reactivity of the low-valent species with *i*PrN=C=NiPr and CO.

Prior to this work, Mg(NON)(THF)<sub>2</sub> was the only reported group 2 metal NON-compound, isolated as a product of over reduction and ligand transfer during the synthesis of a Bi(II) radical.<sup>10</sup> In this work the non-solvated compound was targeted as a precursor to reduced Mg(i) species, using an alkane elimination route between MgBu<sub>2</sub> and (NON)H<sub>2</sub> (Scheme 1). The reaction proceeded smoothly in hexane or toluene, affording colourless crystals of [Mg(NON)]<sub>2</sub> (**1**).

Compound **1** is sparingly soluble in hydrocarbon solvents, preventing the acquisition of meaningful spectroscopic data at room temperature.<sup>11</sup> The crystal structure revealed a dimer located on an inversion centre (Scheme 1). The bidentate ligand adopts a κN<sup>1</sup>,O-μ-N<sup>2</sup>-coordination mode in which the oxygen atom is in a four-membered N–Si–O–Mg metallacycle and the pendant N<sub>2</sub> atom bonds to the symmetry related Mg. We note that the Mg⋯Mg separation of 4.102(1) Å is too great to support a Mg–Mg bond in this dimeric arrangement, necessitating a reorganisation of the ligand to permit formation of the target [(L')Mg–Mg(L')]<sup>2-</sup> unit.

The reduction of **1** by KC<sub>8</sub> in Et<sub>2</sub>O reproducibly forms a new product **A** (Scheme 2). <sup>1</sup>H NMR analysis indicated two distinct sets of ligand resonances in a 1 : 1 ratio that are consistent with a symmetric and a non-symmetric environment at magnesium. This is most clear from the three SiMe<sub>2</sub> singlets that appear at δ<sub>H</sub> 0.38 (12H), 0.04 (6H) and –0.04 (6H). The symmetric environment at magnesium is consistent with a Mg(NON) group with a κN,N'- or κN,O,N'-coordination mode of the

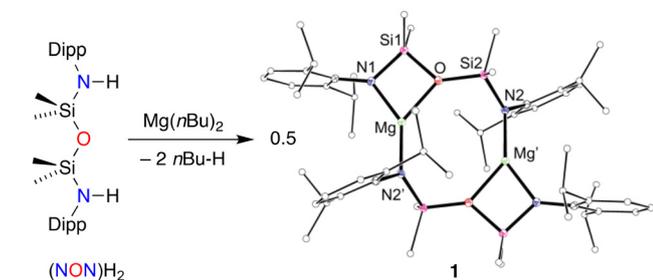
NON-ligand.<sup>10</sup> Based on NMR spectra of a related aluminium system, we attribute the non-symmetric ligand environment to a previously reported intramolecular 1,3-silyl retro-Brook rearrangement of the NON-ligand to form an *N,O*-chelated Mg(NNO) group [(NNO)]<sup>2-</sup> = [N(Dipp)SiMe<sub>2</sub>N(Dipp)SiMe<sub>2</sub>O]<sup>2-</sup>.<sup>12</sup> We are unable to crystallise **A** and cannot therefore assign it a precise chemical structure. Furthermore, analytical data does not allow us to discriminate between a discrete heteroleptic [(NON)Mg–Mg(NNO)]<sup>2-</sup> unit or a mixture that also includes homoleptic [(NON)Mg–Mg(NON)]<sup>2-</sup> and [(NNO)Mg–Mg(NNO)]<sup>2-</sup> species. It is possible that a dynamic equilibrium exists, hindering crystallisation of a single species. However, onward reactivity confirms the presence of both K[Mg(NON)] and K[Mg(NNO)] groups in **A**.

Evidence for **A** reacting as a discrete heteroleptic [(NON)Mg–Mg(NNO)]<sup>2-</sup> unit is inferred from its reaction with diisopropylcarbodiimide to form **2** (Scheme 2). Previous studies with **I** and **II-a** showed that addition of RN=C=NR (R = Cy, *t*Bu) afforded the magnesioamidinate species from the reductive insertion of carbodiimide into a Mg–Mg bond.<sup>1,9c</sup> The proposed mechanism involves initial *N*-coordination of the carbodiimide to one Mg centre, followed by migration of the second Mg to the sp<sup>2</sup> carbon of the carbodiimide.<sup>1,13</sup>

NMR spectra of **2** retain a 1 : 1 ratio of NON- and NNO-ligand resonances, with additional signals for magnetically equivalent NiPr groups, and a high frequency resonance at δ<sub>C</sub> 226.1 for the CN<sub>2</sub> carbon atom. The crystal structure reveals both Mg(NON) and Mg(NNO) groups bridged by a [C(NiPr)<sub>2</sub>]<sup>2-</sup> unit (Fig. 2). The C–N distances in the amidinate unit (1.344(3)–1.358(3) Å) indicate delocalisation in the CN<sub>2</sub> fragment, confirming a two-electron reduction of the carbodiimide. The regiochemistry in **2** is consistent with *N*-coordination of the carbodiimide at the less sterically encumbered Mg(NNO) centre, followed by migration of the Mg(NON) fragment to the carbon atom.<sup>12a</sup>

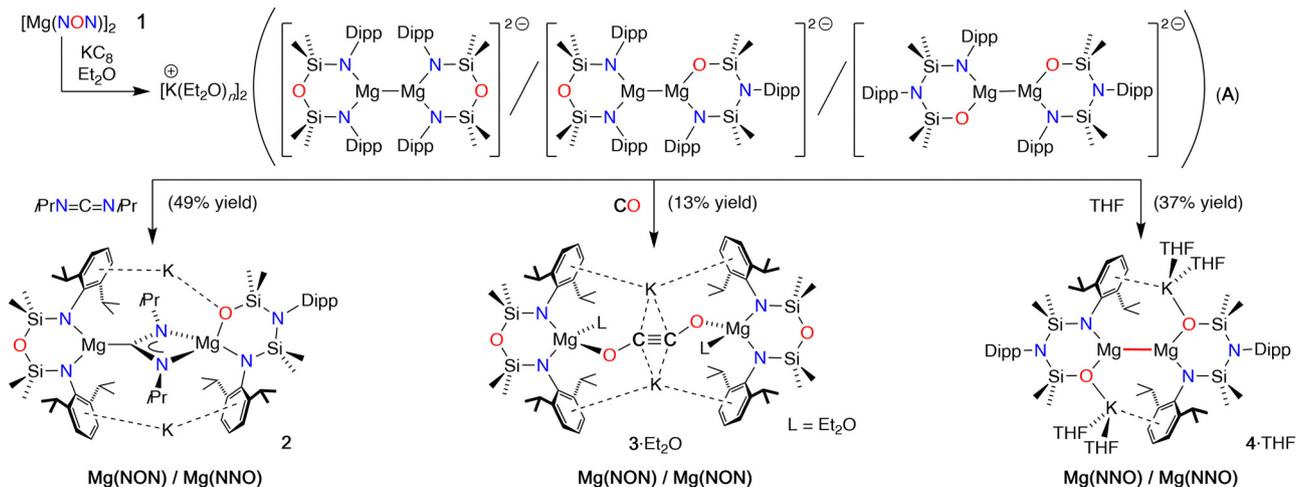
Compounds **III**, **IV** and the aforementioned dimagnesium(μ-N<sub>2</sub>) complex reductively dimerise CO to afford ethynediolate complexes.<sup>5–7</sup> The reaction of **A** with 1 bar CO proceeded with an immediate colour change from yellow to red-orange, affording a low yield of crystals of 3·Et<sub>2</sub>O (Scheme 2). The <sup>1</sup>H NMR spectrum showed only symmetric ligand environments, consistent with Mg(NON) fragments. The <sup>13</sup>C{<sup>1</sup>H} NMR spectrum showed a signal at δ<sub>C</sub> 76.6, downfield of the [C<sub>2</sub>O<sub>2</sub>]<sup>2-</sup> resonances noted in previous ethynediolate products (δ<sub>C</sub> 50.2/55.3).

X-ray diffraction analysis of 3·Et<sub>2</sub>O confirmed formation of the homoleptic ethynediolate complex, K<sub>2</sub>[(Mg(NON)(Et<sub>2</sub>O))<sub>2</sub>(μ-C<sub>2</sub>O<sub>2</sub>)] containing Et<sub>2</sub>O solvated Mg(NON) groups (Fig. 3). Previous studies showing that the isomerisation of Al(NON) to Al(NNO) is exergonic<sup>12a</sup> suggest that the formation of Mg(NNO) groups during the synthesis of **A** is non-reversible. The absence of Mg(NNO) groups in 3·Et<sub>2</sub>O therefore suggests that its formation involves the preferential reaction of CO with the Mg(NON) components of **A**, and may indicate the presence of symmetrical [(NON)Mg–Mg(NON)]<sup>2-</sup> units. The structural parameters of the 'Mg(OC≡CO)Mg' unit closely resemble the previous examples,<sup>5,6,14</sup> with a short C–C bond of 1.211(8) Å and a slight *trans*-bent geometry (O<sub>2</sub>–C<sub>29</sub>–C<sub>29</sub>' = 164.6(6)°).



**Scheme 1** Synthesis and thermal displacement plot (30% probability; H-atoms omitted; peripheral carbons as spheres) of **1** (*r*' = –*x*, 1 – *y*, –*z*). Selected bond lengths (Å) and angles (°): Mg–N1 1.9414(10), Mg–O 2.0605(9), Mg–N2' 1.9542(10), Mg⋯Mg' 4.102(1); N1–Mg–O 77.54(4), N1–Mg–N2' 143.74(5), O–Mg–N2' 138.48(4).





Scheme 2 Formation of **A** and reaction with  $i\text{PrN}=\text{C}=\text{NiPr}$ ,  $\text{CO}$  and  $\text{THF}$  to afford **2**, **3**· $\text{Et}_2\text{O}$  and **4**· $\text{THF}$  (isolated yields reported).

Extraction of **A** with  $\text{THF}$  afforded a mixture of products including  $\text{K}_2[\text{NON}]$ , and the new compound **4**· $\text{THF}$  that was isolated by fractional crystallisation in 37% yield. The  $^1\text{H}$  NMR spectrum of **4**· $\text{THF}$  shows splitting according to a compound containing only  $\text{NNO}$ -ligands. This is confirmed by X-ray diffraction, revealing **4**· $\text{THF}$  as the anionic  $\text{Mg}(\text{i})$  species,  $[(\text{NNO})\text{Mg}-\text{Mg}(\text{NNO})]^{2-}$  charge balanced with two  $[\text{K}(\text{THF})_2]^+$  cations (Fig. 4). This result indicates either an analogous redistribution of the  $[\text{Mg}(\text{L}')^-]$  fragments from a mixture present in **A**, or isomerisation of the  $\text{Mg}(\text{NON})$  group to the more stable  $\text{Mg}(\text{NNO})$  isomer during the extraction with  $\text{THF}$ . There is no residual electron density in the region expected for hydride ligands, confirming formation of the anionic  $\text{Mg}(\text{i})$  compound (Fig. S24, ESI $^\dagger$ ). The  $\text{Mg}-\text{Mg}$  bond length (2.9393(11) Å) is in the range reported for (solvent free)

$(\text{L})\text{Mg}-\text{Mg}(\text{L})$  compounds (2.7907(9)–3.0513(8) Å),<sup>15</sup> and is shorter than found in the anionic  $\text{Mg}(\text{i})$  complexes **II** (3.2077(10) Å/3.2124(11) Å)<sup>5</sup> and **III** (3.1369(15) Å).<sup>14</sup> We attribute the short bond to the reduction in steric stress imparted by the  $\text{NNO}$ -isomer, and the reduction in electron density at  $\text{Mg}$  that results from the high electronegativity of the  $\text{O}$ -ligand.

DFT analysis of **I** and **IV** revealed a non-nuclear attractor (NNA) at the centre point of the  $\text{Mg}-\text{Mg}$  bond.<sup>7,16</sup> This feature was not prominent in the core of **III**,<sup>5</sup> which the authors suggest is best described as a  $[\text{Mg}_2\text{Na}_2]^{4+}$  unit. Investigation of **4**· $\text{THF}$  by DFT (see ESI $^\dagger$  for details) show that the HOMO corresponds to the  $\text{Mg}-\text{Mg}$   $\sigma$ -bond with equal contribution from both metals and a high  $s$ -character of  $\sim 93\%$  (Fig. 5a). Natural bond order (NBO) calculations show a  $\text{Mg}-\text{Mg}$  Wiberg bond index (WBI) of 0.724, with NPA charges  $q_{\text{Mg}} = +1.00$  and  $q_{\text{K}} = +0.88$ . These values compare well with those reported for **III** (WBI = 0.656,  $q_{\text{Mg}} = +1.03$  and  $q_{\text{Na}} = +0.84$ ),<sup>5</sup> and **IV** (WBI = 0.694,  $q_{\text{Mg}} = +0.97$

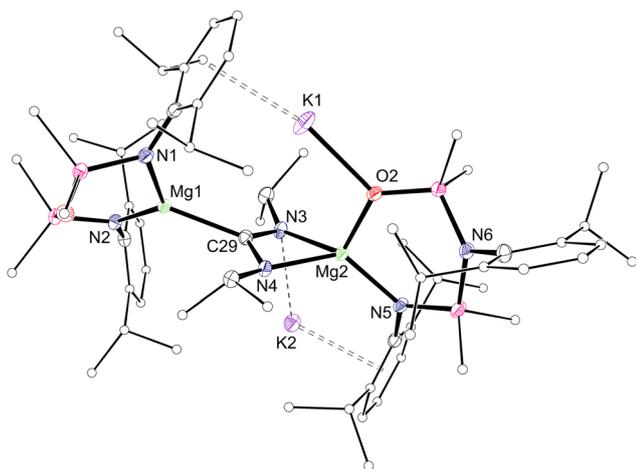


Fig. 2 Thermal displacement plot (30% probability; H-atoms omitted; peripheral carbons as spheres) of one of the independent molecules of **2**. Selected bond lengths (Å) and angles ( $^\circ$ ):  $\text{Mg1}-\text{N1}$  2.0594(19),  $\text{Mg1}-\text{N2}$  2.0415(19),  $\text{Mg2}-\text{N5}$  2.0513(19),  $\text{Mg2}-\text{O2}$  1.9122(16),  $\text{C29}-\text{N3}$  1.358(3),  $\text{C29}-\text{N4}$  1.344(3),  $\text{Mg1}-\text{C29}$  2.232(2),  $\text{Mg2}-\text{N3}$  2.1737(19),  $\text{Mg2}-\text{N4}$  2.069(2),  $\text{N1}-\text{Mg1}-\text{N2}$  123.18(8),  $\text{N5}-\text{Mg2}-\text{O2}$  106.09(8),  $\text{N3}-\text{Mg2}-\text{N4}$  63.51(7).

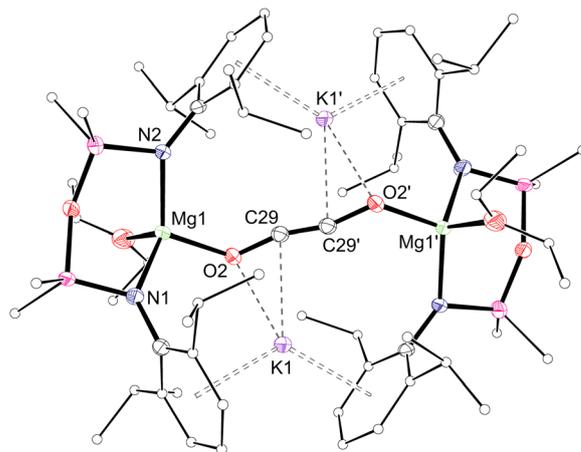


Fig. 3 Thermal displacement plot (30% probability; H-atoms omitted; peripheral carbons as spheres) of one of the independent molecules of **3**· $\text{Et}_2\text{O}$ . Selected bond lengths (Å) and angles ( $^\circ$ ):  $\text{Mg1}-\text{N1}$  2.044(4),  $\text{Mg1}-\text{N2}$  2.049(3),  $\text{Mg1}-\text{O2}$  1.936(3),  $\text{O2}-\text{C29}$  1.309(5),  $\text{C29}-\text{C29}'$  1.211(8),  $\text{N1}-\text{Mg1}-\text{N2}$  121.24(17),  $\text{O2}-\text{C29}-\text{C29}'$  164.6(6).



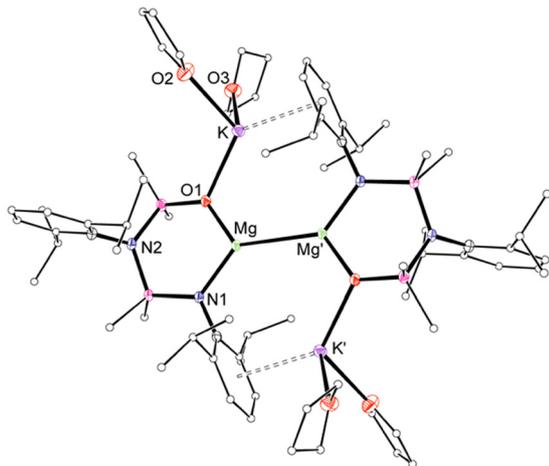


Fig. 4 Thermal displacement plot (30% probability; H-atoms omitted; peripheral carbons as spheres) of **4-THF** ( $' = -x, -y, 2 - z$ ). Selected bond lengths (Å) and angles ( $^{\circ}$ ): Mg–Mg' 2.9393(11), Mg–N1 2.0493(15), Mg–O1 1.9203(13), O1–K 2.5859(13); N1–Mg–O1 106.37(6), N1–Mg–Mg' 131.70(5), O1–Mg–Mg' 121.91(5), Mg–O1–K 109.97(6).

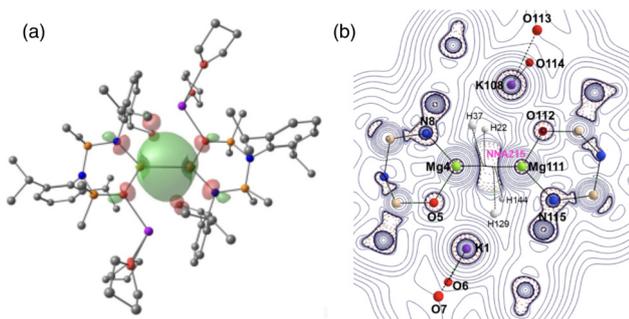


Fig. 5 (a) HOMO of **4-THF**. (b) Laplacian distribution for **4-THF**, showing non-nuclear attractor (NNA215) at the centre of the Mg–Mg bond. Both calculated at the BP86/6-311++G\*\*//BP86/BS1 level of theory.

and  $q_K = +0.90$ ).<sup>6</sup> An NNA of 0.72 electrons is present in the middle of the Mg–Mg bond in **4-THF** (Fig. 5b), similar to that noted in **I** (0.8 electrons).<sup>16</sup>

In conclusion, we have demonstrated that the reduction of the  $[\text{Mg}(\text{NON})]_2$  dimer **1** affords product **A**, formulated as containing  $\text{K}[\text{Mg}(\text{NON})]$  and  $\text{K}[\text{Mg}(\text{NNO})]$  units. Although the composition of **A** has not been explicitly identified and an equilibrium of different species may be present, analytical data and reactivity studies confirm the presence of reducing  $\text{Mg}(\text{NON})$  and  $\text{Mg}(\text{NNO})$  groups. Isolation and structural characterisation of  $[\text{K}(\text{THF})_2]_2[(\text{NNO})\text{Mg}-\text{Mg}(\text{NNO})]$  (**4-THF**) prompted analysis by DFT, showing a non-nuclear attractor of 0.72 electrons at the centre of the Mg–Mg bond. Access to both  $\text{K}[\text{Mg}(\text{NON})]$  and  $\text{K}[\text{Mg}(\text{NNO})]$  groups from **A** may expand the scope of reactivity compared with a system in which only one ligand-type was available. This flexibility imparted by the opportunity to 'mix and match'  $[\text{Mg}(\text{L})]^-$  fragments according to the reaction may be important in stabilising the reduction products and will form part of our ongoing investigations.

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## Data availability

The data supporting this article have been included as part of the ESI†

## Conflicts of interest

There are no conflicts to declare.

## Notes and references

- 1 S. P. Green, C. Jones and A. Stasch, *Science*, 2007, **318**, 1754–1757.
- 2 (a) C. Jones, *Nat. Rev. Chem.*, 2017, **1**, 0059; (b) A. Stasch and C. Jones, *Dalton Trans.*, 2011, **40**, 5659–5672.
- 3 (a) J. T. Boronski, *Dalton Trans.*, 2024, **53**, 33–39; (b) L. A. Freeman, J. E. Walley and R. J. Gilliard, *Nat. Synth.*, 2022, **1**, 439–448; (c) K. M. Fromm, *Coord. Chem. Rev.*, 2020, **408**, 213193.
- 4 (a) Y. Liu, S. Li, X.-J. Yang, P. Yang and B. Wu, *J. Am. Chem. Soc.*, 2009, **131**, 4210–4211; (b) M. Ma, H. Wang, J. Wang, L. Shen, Y. Zhao, W.-H. Xu, B. Wu and X.-J. Yang, *Dalton Trans.*, 2019, **48**, 2295–2299.
- 5 H.-Y. Liu, R. J. Schwamm, S. E. Neale, M. S. Hill, C. L. McMullin and M. F. Mahon, *J. Am. Chem. Soc.*, 2021, **143**, 17851–17856.
- 6 R. Mondal, M. J. Evans, T. Rajeshkumar, L. Maron and C. Jones, *Angew. Chem., Int. Ed.*, 2023, **62**, e202308347.
- 7 R. Mondal, M. J. Evans, D. T. Nguyen, T. Rajeshkumar, L. Maron and C. Jones, *Chem. Commun.*, 2024, **60**, 1016–1019.
- 8 (a) H.-Y. Liu, S. E. Neale, M. S. Hill, M. F. Mahon, C. L. McMullin and B. L. Morrison, *Chem. Commun.*, 2023, **59**, 3846–3849; (b) H.-Y. Liu, S. E. Neale, M. S. Hill, M. F. Mahon, C. L. McMullin and E. Richards, *Angew. Chem., Int. Ed.*, 2023, **62**, e202213670.
- 9 (a) L. Yang, Y. Zhang, Y. Zhao and X.-J. Yang, *Polyhedron*, 2023, **244**, 116632; (b) J. Wang, J. Wang, L. Shen, Y. Zhao, B. Wu and X.-J. Yang, *Organometallics*, 2019, **38**, 2674–2682; (c) L. Yang, Y. Qu, J. Wang, W. Xu, Y. Zhao and X.-J. Yang, *Chem. – Eur. J.*, 2023, **29**, e202301266; (d) H.-Y. Liu, S. E. Neale, M. S. Hill, M. F. Mahon, C. L. McMullin and E. Richards, *Organometallics*, 2024, **43**, 879–888.
- 10 R. J. Schwamm, J. R. Harmer, M. Lein, C. M. Fitchett, S. Granville and M. P. Coles, *Angew. Chem., Int. Ed.*, 2015, **54**, 10630–10633.
- 11  $^1\text{H}$  and  $^{13}\text{C}\{^1\text{H}\}$  NMR spectra recorded at 373 K show a symmetric ligand environment (Fig. S3 and S4, ESI†). The addition of THF to aid solubilisation forms a partially solvated dimer. Further details and related studies with heavier group 2 NON-compounds will be the subject of a forthcoming publication.
- 12 (a) A. O'Reilly, M. G. Gardiner, C. L. McMullin, J. R. Fulton and M. P. Coles, *Chem. Commun.*, 2024, **60**, 881–884; (b) F. Haftbaradaran, G. Mund, R. J. Batchelor, J. F. Britten and D. B. Leznoff, *Dalton Trans.*, 2005, 2343–2345; (c) F. Haftbaradaran, A. M. Kuchison, M. J. Katz, G. Schatte and D. B. Leznoff, *Inorg. Chem.*, 2008, **47**, 812–822.
- 13 L. Xiao, W. Chen, L. Shen, L. Liu, Y. Xue, Y. Zhao and X.-J. Yang, *Chem. Commun.*, 2020, **56**, 6352–6355.
- 14 R. Mondal, K. Yuvaraj, T. Rajeshkumar, L. Maron and C. Jones, *Chem. Commun.*, 2022, **58**, 12665–12668.
- 15 (a) X. Cao, J. Li, A. Zhu, F. Su, W. Yao, F. Xue and M. Ma, *Org. Chem. Front.*, 2020, **7**, 3625–3632; (b) T. X. Gentner, B. Rösch, G. Ballmann, J. Langer, H. Elsen and S. Harder, *Angew. Chem., Int. Ed.*, 2019, **58**, 607–611.
- 16 J. A. Platts, J. Overgaard, C. Jones, B. B. Iversen and A. Stasch, *J. Phys. Chem. A*, 2011, **115**, 194–200.

