# Synthesis, crystal structures and properties of cis- and trans-isomers of [Pt{C<sub>6</sub>H<sub>4</sub>-4R<sup>1</sup>-1-[C<sub>8</sub>H<sub>4</sub>N-3'-NOMe] $Cl_2(dmso)$ ] (R<sup>1</sup> = H or Cl) Concepción López<sup>a,\*</sup>, Carlos Moya<sup>a</sup>, Pradipta K. Basu<sup>b</sup>, Asensio González<sup>b</sup>, Xavier Solans <sup>c</sup>, <sup>†</sup>, Mercè Font-Bardía <sup>c</sup>, Teresa Calvet <sup>c</sup>, Elena Lalinde <sup>d</sup>, M. Teresa Moreno <sup>d</sup> <sup>a</sup> Departament de Quimica Inorgànica, Facultat de Quimica, Universitat de Barcelona, Martí i Franquès 1-11, E-08028 Barcelona, Spain <sup>b</sup> Laboratori de Quimica Orgànica, Facultat de Farmàcia, Universitat de Barcelona, Pl. Pius XII s/n, E-08028 Barcelona, Spain <sup>c</sup> Departament de Cristal·lografia Mineralogía i Dipòsits Minerals, Facultat de Geologia, Universitat de Barcelona, Martí i Franquès s/n, E-08028 Barcelona, Spain <sup>d</sup> Departamento de Química, Grupo de Síntesis Química de La Rioja, UA-CSIC, Universidad de La Rioja, E-26006 Logroño, Spain

## 23 Abstract

24	The study of the reactivity of the 3-methoxyimino-2-phenyl-3H-indoles $C_6H4-4R^1-1-$
25	[C <sub>8</sub> H <sub>4</sub> N-3'-NOMe] [ $\mathbb{R}^1$ = Cl (1a) or H (1b)] with <i>cis</i> -[PtCl <sub>2</sub> (dmso) <sub>2</sub> ] has allowed the
26	isolation of <i>trans</i> -[Pt{C <sub>6</sub> H <sub>4</sub> -4R <sup>1</sup> -1-[C <sub>8</sub> H <sub>4</sub> N-3'-NOMe]}Cl <sub>2</sub> (dmso)][R <sup>1</sup> = Cl ( <b>2a</b> ) or H ( <b>2b</b> )]
27	and <i>cis</i> -[Pt{C <sub>6</sub> H <sub>4</sub> -4R <sup>1</sup> -1-[C <sub>8</sub> H <sub>4</sub> N-3'-NOMe]}Cl <sub>2</sub> (dmso)] -CH <sub>2</sub> Cl <sub>2</sub> [R <sup>1</sup> = Cl ( <b>3a</b> ) or H( <b>3b</b> )].
28	Their crystal structures confirm: (a) the existence of a PtAN <sub>indole</sub> bond, (b) the relative
29	arrangement of the Cl <sup>-</sup> ligands ( <i>trans</i> in <b>2a</b> and <b>2b</b> or <i>cis</i> in <b>3a</b> and <b>3b</b> ) and (c) the <i>anti</i> -(E)
30	configuration of the oxime. A comparative study of the spectroscopic and photo-optical
31	properties of ligands and their platinum(II) complexes (2a, 2b, 3a and 3b) is also reported.
32	
33	
34	
35	
36	
37	
38	
39	
40	
41	
42	
43	
44	

#### 45 1. Introduction

Transition metal complexes containing heterocyclic ligands have a long history of interest because the binding of the metal offers possibilities for tuning the properties of the free ligands [1,2]. The nature of the transition metal, its oxidation state, the electronic and steric characteristics of ligands bound to the metal and their relative disposition modify the physical and chemical properties and have direct implications on the potential utility of metal complexes in a wide range of areas that include Chemistry, Medicine, Biology and Materials Science [3–7].

Furthermore, the interest in novel *cis* and *trans* isomers of  $[Pt(L^2)(L^3)Cl_2]$  or 53  $[Pt(L^2)_2Cl_2]$  complexes with  $L^2$  or  $L^3 = N$  containing heterocycles has increased 54 considerably in recent years. This has been prompted mainly by their chemical or physical 55 properties and their utility as sensors for biomolecules as well as their potential antitumoral 56 activity [8–11]. The synthesis, characterization and structural studies of new types of trans 57 and *cis*  $[Pt(L^1)(L^2)Cl_2]$  or  $[Pt(L^1)_2Cl_2]$  complexes are required to elucidate: (a) the role of 58 the Cl<sup>-</sup> ligands and (b) the lability of the Pt-Cl bonds in the cis and trans isomers of 59  $[Pt(L^1)(L^2)Cl_2]$  or  $[Pt(L^1)_2Cl_2]$  complexes with potential biomedical utility. This may allow 60 to establish relationships between their structures, properties or activities and consequently, 61 it could provide useful tools for the rational design of new and more efficient platinum(II) 62 complexes. 63

Platinum(II) complexes  $[Pt(L^1)(L^2)Cl_2]$  or  $[Pt(L^1)_2Cl_2]$  where  $L^1$  derived from imidazole or pyrazole have been reported [12], but related analogues with indolyl units are scarce [13]. In this work we present the synthesis of *trans* and *cis* isomers of compounds  $[Pt(L^3)Cl_2(dmso)]$  where L3 is one of the two 3-methoxyimino-2-phenyl-3H-indoles (1a and 1b shown in Scheme 1) and a comparative study of their structures and spectroscopic properties.

70

#### 72 **2. Results and discussion**

#### 73 2.1. Synthesis and description of the crystal structures of the complexes

*Trans*-[Pt{C6H4-4R<sup>1</sup>-1-[C8H4N-3'-NOMe]}Cl2(dmso)] [R<sup>1</sup> = Cl(2a) an dH (2b)] 74 were prepared by treatment of the corresponding ligand (1a or 1b) [14] with the equimolar 75 amount of cis-[PtCl<sub>2</sub>(dmso)<sub>2</sub>] [15] in refluxing methanol for 2 h (Scheme 1). Shorter 76 refluxing periods (from 2 h to 0.5 h) produced a significant decrease of the yield [from 87% 77 to 23% (for 2a) or from 73% to 27% (for 2b)]. However, when the reaction time was t = 878 79 h, two different products were isolated for each ligand (Scheme 1). One of them was 2a or 2b; while characterization data of the other ones (3a or 3b) and their crystal structures (see 80  $cis-[Pt{C_6H_4-4R^1-1-[C_8H_4N-3'$ below) indicated that they were 81 NOMe] $Cl_2(dmso)$ ]·CH<sub>2</sub>Cl<sub>2</sub> [R<sup>1</sup> = Cl (**3a**) or H (**3b**)]. 82

The four compounds are air-stable solids at room temperature and were also 83 84 1-[C<sub>8</sub>H<sub>4</sub>N-3'-NOMe]  $Cl_2(dmso)$ ] [R<sup>1</sup> = Cl (2a) or H (2b)] (Figs. 1 and 2) showed that the 85 platinum(II) atom is located in a slightly distorted square-planar environment bound to the 86 87 heterocyclic nitrogen, the sulfur atom of the dmso ligand and the two mutually trans chloride ligands [Cl(1)-Pt-Cl(2) 175.95(5)° (in 2a) and 177.65(4)° (in 2b)]. In both complexes bond 88 lengths and angles around the platinum(II) (Table 1) fall in the range reported for related 89 *trans*-[Pt( $L^1$ )Cl<sub>2</sub>(dmso)] complexes with  $L^1$  = N-donor heterocyclic ligand [16,17] and the 90 coordination plane of the platinum(II) forms angles of 73.76° (2a) and of 98.30° (2b) with 91 the heterocycle. 92

The molecules of 2a and 2b differ in the orientation of the substituents of the dmso
ligand in relation to the Cl<sup>-</sup> ligands, [torsion angles C(16)-S-Pt-Cl(1) and C(17)-S-Pt-Cl(1)
are: 147.25° and 37.3° (in 2a) and 57.0° and 53.06° (in 2b)].

In the crystals of 2a, two parallel and proximal molecules of *trans*-[Pt{C<sub>6</sub>H<sub>4</sub>-4Cl-1-[C<sub>8</sub>H<sub>4</sub>N-3'-NOMe]}Cl<sub>2</sub>(dmso)] with a *head* to-*head* orientation are connected by two C(9)-H(9C)···N(2) interactions [distances: H(9C)···N(2) = 2.67 Å and C(9···N(9) = 3.61 Å and angle C(9)-H(9C)···N(2) = 167.6°] forming dimers containing a central eight membered ring (Fig. 3a) through a typical  $R_2^2$  (8) hydrogen bond system [4b]. This type of hydrogen bond pattern is quite frequent for N-heteroaromatic molecules [16] such as dibromodiquinoline [18], but examples involving aliphatic C-H bonds are not common [16].

103 The orientation of the dmso ligands in each dimer permits the existence of a pair of 104 bifurcated C-H  $\cdots$  O intermolecular interactions between the oxygen O(2) and the H(13) 105 and H(17C) atoms of two different molecules [distances: O(2)  $\cdots$  H(13) = 2.51 Å, O(2)  $\cdots$ 106  $\cdot$  C(13) = 3.318 Å, O(2)  $\cdots$  H(17C) = 2.53 Å and O(2)  $\cdots$  C(17C) = 3.416 Å] (Fig. 3b). 107 These weak interactions allow the connectivity between a molecule of the dimer and two 108 units belonging to two different dimeric units.

For this arrangement of groups the separations between the Cl(1) and Cl(2) bound to the metal and the H(11) and H(16) atoms, respectively, of two different molecules (2.854 Å and 2.872 Å, respectively) are smaller than the sum of the van der Waals radii of these atoms (1.70 Å and 1.20 Å for Cl and H, respectively) [19], and fall in the range expected for C-H  $\cdots$  Cl hydrogen bonds (from 2.40 to 2.90 Å) [3,16]. As a consequence of these interactions a three dimensional network results.

In the crystal of **2b** the arrangement of two vicinal molecules is such that the H(14) atom of one of the molecules is at 3.58 Å of the centroid of the ring defined by the set of atoms [C(1)-C(6)] of the other unit, thus suggesting the existence of weak CAH p interactions [3,4,16]. This arrangement of groups precludes the existence of CAH N interactions similar to those found in **2a**, but enables short contacts between the chloride ligands [Cl(1) and Cl(2)] of a molecule and two CAH bonds [C(5)AH(5) and C(2)AH(9A), respectively] of two different units located in the upper and lower plane.

The distances Cl(1) H(5) (2.86 Å), Cl(1) C(5) (3.634 Å), Cl(2) H(9A) (2.82 Å) and Cl(2) C(9) (3.623 Å) are consistent with the typical values expected for non-conventional CAH Cl bonds [3–5,16]. As a consequence of these weak interactions the assembly of the molecules results in a chain (Fig. 4). Two proximal chains are connected by two CAH O bonds, involving the O(2) atom and the H(16C) atom of the dmso, that generate an eight membered ring {graph set notation R22 (8) [4b]}.

128 Despite the formal similarity between **2a** and **2b** their structural motifs are different. 129 The assembly of vicinal molecules is achieved by  $C-H \cdot \cdot \cdot N$  (in **2a**) or weak  $C-H \cdot \cdot \pi$  (in 130 **2b**) intermolecular interactions. Furthermore, in the resulting units of **2b**, the Cl<sup>-</sup> ligands are involved in non-conventional C–H···Cl bonds. The relative arrangement of the substituents of the dmso ligand in the two products plays a key role in the crystal packing since it modifies the connectivity between structural units forming bifurcated C–H···O bonds (in **2a**) or eight-membered rings (in **2b**).

The crystals of *cis*-[Pt{C<sub>6</sub>H<sub>4</sub>-4R<sup>1</sup>-1-[C<sub>8</sub>H<sub>4</sub>N-3'-NOMe]}Cl<sub>2</sub>(dmso)] [R<sup>1</sup> = Cl (**3a**) or 135 H (**3b**)] contain a 1:1 array of [Pt{C<sub>6</sub>H<sub>4</sub>-4R<sup>1</sup>-1-[C<sub>8</sub>H<sub>4</sub>N-3'-NOMe]}Cl<sub>2</sub>(dmso)] [R<sup>1</sup> = Cl 136 (3a) or H (3b)] (Figs. 5 and 6, respectively) and CH<sub>2</sub>Cl<sub>2</sub> molecules. In the two cases, the 137 coordination sphere of the platinum(II) is similar to those of 2a and 2b, except for the relative 138 *cis* arrangement of the two Cl<sup>-</sup> ligands [Cl(1) APtACl(2) bond angles are 90.07(8)° (in **3a**) 139 140 and 90.94(7)° (in **3b**)]. Bond lengths and angles around the platinum(II) (Table 1) agree with those reported for cis-[Pt( $L^1$ )Cl<sub>2</sub>(dmso)] complexes with  $L^1$  = N-donor heterocyclic ligand 141 [16,17,20]. The variations detected in the PtACl(1) and PtACl(2) bond lengths in **3a** and 3b 142 when compared with those obtained for 2a and 2b could be due to the different influence of 143 144 the ligands in a *trans* disposition [20].

In the crystal architecture of **3a**, dichloromethane has an interesting role because two 145 betweentwo  $[Pt{C_6H_4-4Cl-1-[C_8H_4N-3'-$ 146 CH<sub>2</sub>Cl<sub>2</sub> molecules act as connectors NOMe]}Cl2(dmso)] units with a head-to-tail orientation (Fig. 7). The assembly depicted in 147 Fig. 7 arises from the existence of two complementary  $C-H \cdot \cdot \cdot X$  (X = Cl or O) interactions. 148 149 First, non-conventional hydrogen bonds involving the Cl(4) atom of the CH<sub>2</sub>Cl<sub>2</sub> and the H(11) atom of the phenyl ring [distances Cl(4)  $\cdot \cdot \cdot$  H(11) = 2.83 Å and Cl(4)  $\cdot \cdot \cdot$  C(11) = 150 3.601 Å and angle  $Cl(4) \cdot \cdot \cdot H(11) - C(11) = 140.9^{\circ}$ ]. Second, the separation between the 151 H(18A) atom of both CH<sub>2</sub>Cl<sub>2</sub> molecules and the oxygen of the dmso ligand [distances O(2)] 152 -H(18A) = 2.17 Å and  $O(2) \cdot \cdot \cdot C(18) = 3.045$  Å] and their relative orientations [angle 153  $C(18) - H(18A) \cdots O(2) = 148.6^{\circ}$  are consistent with the values reported for (C–H)phenyl 154  $\cdots$  O(dmso) interactions in transition metal complexes [4a,16,21]. 155

Thus, in this case there is a cooperative assembly between two molecules of CH<sub>2</sub>Cl<sub>2</sub> and two molecules of *cis*-[Pt{C<sub>6</sub>H<sub>4</sub>-4Cl-1-[C<sub>8</sub>H<sub>4</sub>N-3'-NOMe]}Cl<sub>2</sub>(dmso)] resulting in  $R_4^4$  (22) hydrogen bonding pattern. According to data available at the *Cambridge*  159 Crystallographic Data Centre compounds containing CH<sub>2</sub>Cl<sub>2</sub> acting as "linkers" between other molecules via simultaneous  $C-H \cdot \cdot \cdot O$  and  $(C-H)_{phenvl} \cdot \cdot \cdot Cl$  intermolecular 160 interactions are not common [16,22]. The crystal structure of cis-[Ru(L<sup>4</sup>)Cl<sub>2</sub>(dmso)] · 161  $CH_2Cl_2 [L^4 = bis(diphenylphosphino)phenylether]$  also reveals the existence of both types 162 of short contacts [22], but the relative arrangement of the CH<sub>2</sub>Cl<sub>2</sub> molecules is different 163 from that found for **3a**, where the assembly leads to dimeric units {*cis*-[Pt{C<sub>6</sub>H<sub>4</sub>-4Cl-1-164 165  $[C_8H_4N-3'-NOMe]$  Cl2(dmso)] · CH2Cl2 in which the CH2Cl2 molecules can be visualized as bridges between two molecules of the platinum(II) complex. As far as we 166 know, complexes showing an  $R_4^4$  (22) hydrogen bond pattern similar to that found in **3a** have 167 not been described before. Additionally, in the crystal of 3a, the separation between the Cl(1) 168 169 atoms of the molecules defining the dimers and the H(16) atom of two close ones is [Cl(1)].  $\cdot \cdot H(16) = 2.854$  Å] indicates weak C–H  $\cdot \cdot \cdot Cl$  intermolecular interactions between the 170 molecules that assemble giving a three dimensional network. Despite the quality of the 171 crystal of **3b** was poorer<sup>1</sup> than that of **2b**, its crystal structure reveals some interesting 172 differences. In **3b** the relative arrangement of two molecules of *trans*-[Pt{C<sub>6</sub>H<sub>5</sub>-1-[C<sub>8</sub>H<sub>4</sub>N-173 3'-NOMe]{Cl2(dmso)] with a head-to-tail orientation are connected through the dmso 174 ligands by two bifurcated weak C-H  $\cdot \cdot \cdot$  O interactions [separations O(2)  $\cdot \cdot \cdot$  H(16A) = 175 2.657 Å and  $O(2) \cdot \cdot \cdot H(17C) = 2.608$  Å] (Fig. 8). This type of assembly is quite common 176 especially in the crystal structures of complexes having dmso molecules as solvation [16,23]. 177 178 Examples of cycloplatinated complexes derived from planar N-donor ligands exhibiting a 179 similar arrangement have also been described [24].

It should be noted that the crystal structures of the four complexes 2a,b and 3a,b 180 exhibit the following common features: (a) the two rings of the indole moiety are nearly 181 coplanar (angles between their main planes being 4.8°, 1.4°, 3.0° and 1.2° in 2a, 2b, 3a and 182 **3b**), (b) the ligand (**1a** or 1b) adopts the *anti*-(E) configuration, (c) the oxime moiety is 183 practically coplanar with the pentagonal ring (angles defined by their main planes =  $3.3^{\circ}$ , 184 1.5°, 1.1° and 3.4° for **2a**, **2b**, **3a** and **3b**, respectively) and (d) the phenyl rings defined by 185 the set of atoms [C(10)-C(16)] are twisted in relation to the pentagonal ring [angles between 186 planes =  $43.0(2)^{\circ}$ ,  $47.5(2)^{\circ}$ ,  $49.9(4)^{\circ}$  and  $51.8(4)^{\circ}$ , respectively]. As a consequence of 187 these arrangements of groups: (a) the nitrogen of the "=N-OMe" unit is close to the H(15) 188

atom of the phenyl ring [distances  $N(2) \cdots H(15) = 2.666, 2.679, 2.777$  and 2.879 Å for **2a**, **2b**, **3a** and **3b**, respectively] and (b) the separation between the H(5) and the O(1) atoms and the value of the angle C(5) – H(5)  $\cdots$  O(1) (Table 1) suggest a C – H  $\cdots$  O intramolecular interaction resulting in a S(6) hydrogen bond system [4b].

193

#### 194 *2.2. Solution studies*

195 Compounds **2a,b–3a,b** are soluble in CH<sub>2</sub>Cl<sub>2</sub> and CHCl<sub>3</sub>, but the solubilities of **3a** 196 and **3b** are greater than those of *trans* isomers (**2a** and **2b**, respectively). The four products 197 were characterized in solution by mono- and two dimensional NMR (see Section 4).

<sup>1</sup>H NMR spectra showed a singlet in the range  $4.0 < \delta < 5.0$  ppm, due to the OMe unit. As expected, for the *trans* isomers (**2a** and **2b**) the methyl groups of the dmso ligand were equivalent; while they were diastereotopic in the *cis* isomers (**3**). For **3a** and **3b**, one of the resonances appeared in the same range as for **2a** and **2b**; while the other one was upfieldshifted (*ca*. 0.9 ppm). This finding can be due to the anisotropy of one of the aromatic rings close to this Me group.

The low field region of the <sup>1</sup>H and <sup>13</sup>C{<sup>1</sup>H} NMR spectra was complex and the complete assignment of the signals was achieved with the aid of { $^{1}H-{}^{1}H$ } COSY and NOESY and { $^{1}H-{}^{13}C$ } HSQC and HMBC experiments.

The shift of the signal due to the H(5) proton in the <sup>1</sup>H NMR spectra of **2a,b–3a,b** (see Section 4), suggests that the C(5) – H(5) · · · O(1) intermolecular interaction present in the crystals (see above) remains in CDCl<sub>3</sub>.

The chemical shift of the singlet detected in the <sup>195</sup>Pt{<sup>1</sup>H} NMR spectra of **2a**, **2b**, **3a** and **3b** (in the range  $-2959 > \delta > -3022$  ppm) was consistent with the values reported for other complexes where the platinum(II) has a "Pt(N)Cl<sub>2</sub>(S<sub>dmso</sub>)" environment [9,25]. Since it is well-known that an upfield shift of the signals due to <sup>195</sup>Pt is related to a stronger interaction between the platinum(II) and the ligands [25], the comparison of the <sup>195</sup>Pt chemical shift for the trans configured isomers [ $\delta = -3022$  (for **2a**) and -3015 (for **2b**)] and their isomeric cis forms [ $\delta = -2965$  (for **3a**) and -2959 (for **3b**)] indicates that the strength of these interactions is greater in **2a** and **2b**.

It should be noted that no significant change was observed in the <sup>1</sup>H NMR spectra of freshly prepared solutions and those kept after 5 days, thus suggesting that the new products are stable in CDCl<sub>3</sub> (or CH<sub>2</sub>Cl<sub>2</sub>) solutions and they are not prone to isomerize at 298 K.

One of the main interests in phenylindole derivatives arise from their potential luminescence [1], that makes them useful for fluorescence imaging microscopy and for labeling of biomolecules such as DNA [26]. On the other hand, some square-planar platinum(II) complexes are photoluminescent with emissive states usually arising from intraligand  $\pi \rightarrow \pi^*$  (IL), metal-to-ligand charge transfer (MLCT) or even ligand-to-ligand charge transfer (LL'CT) [27,28]. In view of these facts, we also studied the effect produced by platinum(II) center on the spectroscopic properties of these new ligands.

The absorption spectra of the ligands (1a, 1b) and compounds 2a,b–3a,b were recorded in CH<sub>2</sub>Cl<sub>2</sub>, and their main features are summarized in Table 2. For comparison purposes data of the precursors C<sub>6</sub>H<sub>5</sub>-4R<sup>1</sup>-1-[C<sub>8</sub>H<sub>4</sub>N-3'-NOH] [R<sup>1</sup> = Cl (4a) or H (4b)] used in the preparation of ligands 1a and 1b [14] are also included.

232 The Uv–vis. spectra of **1a**,**b** and **4a**,**b** displayed the typical three intense bands due to  $\pi \rightarrow \pi^*$  transitions of the heterocyclic unit [1]. The Uv–vis. spectra of the platinum(II) 233 234 complexes showed three (for 3a and 3b) or four (for 2a, 2b) bands. The bands in the range  $269 < \lambda < 275$  nm appear at similar energies to those observed for the free ligands; while 235 those at around 347 and 424 nm are shifted to lower energies than in 1a or 1b and could be 236 237 assigned to metalperturbed intraligand transitions. For the trans isomers of [Pt{C<sub>6</sub>H<sub>4</sub>-4R-1-[C8H4N-3'-NOMe]{Cl2(dmso)] (2a, 2b) an additional band at around 252 nm was also 238 observed. 239

Ligands 1 are not luminescent in the solid state (298 K, 77 K) or the glassy state (77 K) in CH<sub>2</sub>Cl<sub>2</sub>, but they are photoluminescent in fluid (CH<sub>2</sub>Cl<sub>2</sub> solutions) at 298 K. As observed in Fig. 9a, upon excitation of a 5 x  $10^{-5}$  M solution of 1b at  $\lambda \sim 400$  nm, a very weak emission centered at 450 nm was observed. However, excitation in the next higher energy absorption band (~305–330 nm) resulted in a dual emission at 375 nm (maximum) and at 430 nm (broad shoulder). For a  $10^{-3}$ M solution of **1b**, a similar emission pattern was observed by excitation at  $\lambda_{exc} \sim 302$  nm; while the low energy band was selectively observed at ~470 nm when  $\lambda_{exc}$  was 385 nm (Fig. 9b). The excitation spectrum monitored at the low energy band (450–470 nm) resembles the absorption spectrum, pointing that the emissive states come from the same absorbing species.

Ligand **1a** showed a similar behavior (Fig. 10), except that the low energy feature was only clearly visible by using  $10^{-3}$  M solutions. Energy emission bands of **1a** appeared at slightly greater wavelengths than for **1b**. Although lifetimes could not be measured due to the low intensity of these emissions, they are tentatively assigned to be  $\pi \rightarrow \pi^*$  excited states of phenylindole and the oxime units.

255 Unfortunately, the platinum complexes 2 and 3 are not luminescent in solution and also in the solid state neither at room temperature (298 K) nor at low temperature (CH<sub>2</sub>Cl<sub>2</sub> 256 glass, 77 K). Previous studies on photophysical properties of platinum(II) complexes have 257 shown that these properties are dependent on a wide variety of factors among which the 258 259 nature of the ligands bound to the Pt(II) as well as the existence of Pt  $\cdots$  Pt and/or  $\pi \cdots \pi$ interactions between vicinal molecules appear to play a crucial role [27,28]. For compounds 260 2a,b and 3a,b: (a) the shortest distance between proximal platinum(II) ions (8.486, 6.364, 261 7.263 and 7.815 Å, respectively) allows us to discard the existence of any interaction 262 between them and (b) strong  $\pi \cdot \cdot \cdot \pi$  interactions were not observed in their crystal 263 264 structures. Thus, from the above observations we assumed that the lack of luminescence of 2a, 2b, 3a and 3b may be attributed to the low field nature of the ligands bound to the Pt(II). 265

266

#### 268 **3.** Conclusions

A series of neutral 2-phenylindole platinum(II) complexes were synthesized and characterized. X-ray crystal structures of these new products have allowed us to: (a) confirm the mode of binding of the ligands in the complexes, (b) the relative arrangement of the Cl<sup>-</sup> ligands in the isomers of  $[Pt{C_6H4-4R^1-1-[C_8H4N-3'-NOMe]} Cl_2(dmso)]$  and (c) existence of a C(5)–H(5)···O(1) intramolecular interaction [S(6) hydrogen bond pattern] in the four complexes [**2a**,**b** and **3a**,**b**] and consequently a nearly coplanar arrangement of the indolyl unit and the heteroatoms of the oxime.

Additionally, we have also proved that the nature of the substituent  $R^1$  (Cl or H), the 276 relative arrangement of the two Cl<sup>-</sup> ligands [trans (in 2a and 2b) or cis (in 3a and 3b)] and 277 278 the crystallization solvent (in 3a) are important to induce significant modifications in the type, pattern and directionability of the C–H $\cdot$  · Cl, C–H $\cdot$  · N or C–H $\cdot$  · O intermolecular 279 interactions. Moreover, these studies provided conclusive evidence of the relevancy of the 280 coordinated dmso ligand in the crystal architecture. From the structural point of view, 281 product **3a** is especially interesting because it is an adduct with an uncommon  $R_4^4$  (22) 282 hydrogen bonding motif formed by complementary  $C-H \cdot \cdot \cdot O$  and  $C-H \cdot \cdot \cdot Cl$  interactions 283 that link the coordinated dmso ligands of two molecules of cis-[Pt{C6H4-4Cl-1-[C8H4N-3'-284 NOMe]{Cl2(dmso)] with two CH2Cl2 units. The strong tendency of these platinum(II) 285 complexes to establish different types of intermolecular interactions may be relevant in view 286 of their potential utility as sensors for Biomolecules 287

The study of the photophysical properties revealed that ligands **1a** and **1b** exhibit a weak dual emission in CH<sub>2</sub>Cl<sub>2</sub>, but unfortunately, none of the platinum complexes are emissive, neither in solution (CH<sub>2</sub>Cl<sub>2</sub> at 298 K) nor in solid state, probably due to the presence of the low-field nature of the monodentate ligands (Cl<sup>-</sup> and dmso) bound to the platinum(II), which facilitate fast nonradiative decay to the ground state.

Finally, it should be noted that since recent studies have enhanced the interest in developing 2-phenylindole derivatives as a new class of anticancer drugs [29], compounds **2a,b** and **3a–b** appear to be excellent candidates to evaluate the influence of: (a) the binding

296	of the nitrogen heterocycle and (b) the relative arrangement of the Cl <sup>-</sup> ligands in the cis and
297	trans isomers on their potential antitumoral activity. Further work on this field is currently
298	under way.
299	
300	
301	
302	
303	

#### 304 4. Experimental

#### 305 *4.1. Materials and techniques*

306 *Cis*-[PtCl<sub>2</sub>(dmso)<sub>2</sub>] and the ligands (1a and 1b) were prepared as reported previously [14,15]. The remaining reagents were obtained from commercial sources and used as 307 received. Except methanol (that was HPLC grade), the solvents were dried and distilled 308 before use [30]. Elemental analyses (C, H, N, S) were carried out on a Carlo Erba EA1108 309 apparatus. Mass spectra (ESI<sup>+</sup>) were performed with a LC/MSD-TOF spectrometer using a 310 H<sub>2</sub>O/CH<sub>3</sub>CN (1:1) mixture to introduce the sample. Infrared spectra were obtained with a 311 Nicolet 400FTIR instrument using KBr pellets. High resolution <sup>1</sup>HNMRspectra and the two-312 dimensional  $[{^{1}H}-{^{1}H}]$ -NOESY and COSY and  ${^{1}H}-{^{13}C}$ -HSQC and HMBC]experiments 313 were registered with a Varian VRX-500 or a Bruker Avance DMX-500 MHz instruments at 314 298 K. The chemical shifts ( $\delta$ ) are given inppmand the coupling constants (J) in Hz. 315  $^{195}$ Pt{ $^{1}$ H} NMR spectra were obtained with a Bruker-250 MHz instrument at 298 K. In all 316 317 cases the solvent for the NMR experiments was CDCl<sub>3</sub> (99.9%) and the references were SiMe4 [for <sup>1</sup>H and <sup>13</sup>C{<sup>1</sup>H} NMR] and H<sub>2</sub>[PtCl<sub>6</sub>] [ $\delta^{195}$ Pt{H<sub>2</sub>[PtCl<sub>6</sub>]} = 0.0, for <sup>195</sup>Pt{<sup>1</sup>H} 318 NMR]. UV–vis spectra of 10<sup>-4</sup> M solution of **1a,b–4a,b** in CH<sub>2</sub>Cl<sub>2</sub> were recorded at 298 K 319 with a Cary 100 scan Varian UV spectrometer. The optical absorption spectrawere recorded 320 using aHewlett-Packard 8453 (solution) spectrophotometer in the visible and near-UV 321 ranges. Emission and excitation spectra were obtained on a Jobin-Yvon Horiba Fluorolog 322 3-11 Tau-3 spectrofluorimeter. 323

324

325 4.2. Synthesis of trans-[
$$Pt\{C_{6}H_{4}-4R^{1}-1-[C_{8}H_{4}N-3'-NOMe]\}Cl_{2}(dmso)$$
][ $R^{1} = Cl(2a)$  or H  
326 (2b)]

327 *Cis*-[PtCl<sub>2</sub>(dmso)<sub>2</sub>] (231 mg,  $5.5 \times 10^{-4}$  mol) was suspended in 30 mL of methanol and 328 refluxed until complete dissolution. Then, the hot solution was filtered directly on a solution 329 containing  $5.5 \times 10^{-4}$  mol of **1a** (149 mg) or **1b** (129 mg) in 5 mL of methanol and the 330 resulting reaction mixture was refluxed for 2 h. After this period, the undissolved materials 331 were removed by filtration and discarded and the filtrate was concentrated on a rotary evaporator to *ca*. 15 mL and then allowed to cool at room temperature. The pale orange (for 332 **1a**) or yellow (for **1b**) solid formed was collected by filtration, washed with (2x5 mL) 333 portions of methanol and air dried for 1 day and afterwards dried in vacuum for 2 days. 334 Yields: 290 mg (86%) for 2a and 227 mg (71%) for 2b. Characterization data for 2a: Anal. 335 calc. for C17H17Cl3N2O2PtS: C 33.21, H 2.79, N 4.56 and S 5.22%. Found: C 33.1, H 2.8, 336 N, 4.6 and S 5.3%. MS(ESI<sup>+</sup>):  $m/z = 614.9\{[M]+H\}^+$ . IR(selected data):  $v_{max} = 2997$  and 337 2937 [ $\nu$ (C–H)], 1585 [ $\nu$ (>C=N–)] cm<sup>-1</sup>. <sup>1</sup>H NMR data:  $\delta_{\rm H} = 3.39$ [s, <sup>3</sup>J<sub>Pt,H</sub> = 19, 6H, 338 2Me(dmso)], 4.38(s, 3H, OMe), 7.45(td, <sup>3</sup>J<sub>H,H</sub> = 7.8 and <sup>4</sup>J<sub>H,H</sub> = 1.1, 1H, H<sup>6</sup>), 7.60(d, <sup>3</sup>J<sub>H,H</sub> 339 = 7.5, 2H,  $H^{12}$  and  $H^{14}$ ), 7.62(td,  ${}^{3}J_{H,H}$  = 7.8 and  ${}^{4}J_{H,H}$  = 1.1, 1H,  $H^{7}$ ), 8.05(dd,  ${}^{3}J_{H,H}$  = 340 7.8 and  ${}^{4}J_{H,H} = 1.0, 1H, H^{5}$ ), 8.38(dd,  ${}^{3}J_{H,H} = 7.8$  and  ${}^{4}J_{H,H} = 1.0, 1H, H^{8}$ ) and 8.45(d, 341  ${}^{3}J_{H,H} = 7.5, 2H, H^{11} \text{ and } H^{15}$ ).  ${}^{13}C\{{}^{1}H\}$  NMR data:  $\delta_{C} = 43.7[Me(dmso)], 66.1(OMe),$ 342  $120.2(C^9)$ ,  $121.9(C^8)$ ,  $127.3(C^5)$ ,  $128.5(C^4)$ ,  $128.8(C^{12} \text{ and } C^{14})$ ,  $138.8(C^{13})$ ,  $129.3(C^6)$ , 343  $132.4(C^7)$ ,  $133.0(C^{11} \text{ and } (C^{15})$ ,  $150.7(C^3)$ ,  $152.5(C^{10})$  and  $168.0(C^2)$ . 195Pt{<sup>1</sup>H} NMR 344 data:  $\delta_{Pt} = -3022$ . For **2b**: Anal. calc. for C<sub>17</sub>H<sub>18</sub>Cl<sub>2</sub>N<sub>2</sub>O<sub>2</sub>PtS: C 35.18, H 3.13, N 4.83 and 345 S 5.52%. Found: C 35.0, H 3.1, N 4.75 and S 5.5%.  $MS(ESI^+)$ :  $m/z = 581.4\{[M]+H\}^+$ . IR 346 (selected data):  $v_{\text{max}} = 3003$  and  $2937[\nu(\text{C}-\text{H})]$  and  $1602[\nu(>\text{C}=\text{N})] \text{ cm}^{-1}$ . <sup>1</sup>H NMR data: 347  $\delta_{\rm H} = 3.39$ [s, <sup>3</sup>J<sub>PLH</sub> = 19, 6H, 2Me(dmso)], 4.38(s, 3H, OMe), 7.41(td, <sup>3</sup>J<sub>H,H</sub> = 7.8 and <sup>4</sup>J<sub>H,H</sub> 348 = 1.1, 1H,  $H^{6}$ ), 7.58–7.70(m, 4H,  $H^{7}$ ,  $H^{12}$ ,  $H^{13}$  and  $H^{14}$ ) and 8.03(dd,  ${}^{3}J_{H,H}$  = 7.7 and  ${}^{4}J_{H,H}$ 349 = 1.0, 1H,  $H^5$ ), 8.38(dd,  ${}^{3}J_{H,H}$  = 7.7 and  ${}^{4}J_{H,H}$  = 1.0, 1H,  $H^8$ ) and 8.44(dd,  ${}^{3}J_{H,H}$  = 7.5 and 350 <sup>4</sup>J<sub>H,H</sub> = 1.2, 2H,  $H^{11}$  and  $H^{15}$ ). <sup>13</sup>C{<sup>1</sup>H} NMR data:  $\delta_{\rm C} = 43.8[Me({\rm dmso})], 66.4(OMe),$ 351  $120.3(C^9)$ ,  $122.0(C^8)$ ,  $127.5(C^5)$ ,  $128.6(C^4)$ ,  $128.8(C^{12} \text{ and } C^{14})$ ,  $129.2(C^6)$ ,  $132.7(C^7)$ , 352 133.1( $C^{11}$  and  $C^{15}$ ), 139.1( $C^{13}$ ), 150.8( $C^{3}$ ), 152.5( $C^{10}$ ) and 168.5( $C^{2}$ ). <sup>195</sup>Pt{<sup>1</sup>H} NMR 353 data:  $\delta_{Pt} = -3015$ . 354

355

357 4.3. Synthesis of cis-[Pt{C<sub>6</sub>H<sub>4</sub>-4 $R^{1}$ -1-[C<sub>8</sub>H<sub>4</sub>N-3'-NOMe]}Cl<sub>2</sub>(dmso)]·CH<sub>2</sub>Cl<sub>2</sub> [ $R^{1}$  = Cl 358 (**3a**) or H (**3b**)]

These products were isolated using the same procedure as described above for the 359 trans isomers (2a and 2b) but in these cases the reaction mixture was refluxed for 8 h. After 360 361 this period, the solution was concentrated to dryness on a rotary evaporator. The residue was dissolved in the minimum amount of CH<sub>2</sub>Cl<sub>2</sub> and passed through a short (3.0 mm x 2.5 mm) 362 SiO<sub>2</sub> column. Elution with CH<sub>2</sub>Cl<sub>2</sub> produced two bands. The first one gave, after work up, 363 the corresponding *trans*-[Pt{C<sub>6</sub>H<sub>4</sub>-4R<sup>1</sup>-1-[C<sub>8</sub>H<sub>4</sub>N-3'-NOMe]}Cl<sub>2</sub>(dmso)] [with  $R^1 = Cl_2$ 364 (2a), (205 mg) or H (2b), (169 mg)]; while the second one yielded small amounts of 365 366 compounds 3a (73 mg) or 3b (65 mg). Characterization data for 3a: Anal. calc. for C17H17Cl3N2O2PtS·CH2Cl2: C, 30.90; H, 2.74; N, 4.00 and S, 4.58. Found: C 31.0, H 2.8, 367 N 3.95 and S 4.7%. MS(ESI<sup>+</sup>):  $m/z = 636.9\{[M]-CH_2Cl_2 + Na\}^+$ . IR (selected data):  $v_{max}$ 368 = 2902 [ $\nu$ (C–H)] and 1637 [ $\nu$ (>C=N–)] cm<sup>-1</sup>. <sup>1</sup>H NMR data:  $\delta_{\rm H}$  = 2.66[s, 3H, <sup>3</sup>J<sub>Pt,H</sub> = 369 20.6, Me(dmso)], 3.32[s, <sup>3</sup>J<sub>Pt,H</sub> = 21.2, 3H, Me(dmso)], 4.38(s, 3H, OMe), 5.13(s, 2H, 370 CH<sub>2</sub>Cl<sub>2</sub>), 7.43(td,  ${}^{3}J_{H,H} = 7.6$  and  ${}^{4}J_{H,H} = 1.0$ , 1H,  $H^{6}$ ), 7.62(td, J = 7.6 and 1.0, 1H,  $H^{7}$ ), 371 7.65(d,  ${}^{3}J_{H,H} = 7.9, 2H, H^{12}$  and  $H^{14}$ ), 8.18(dd,  ${}^{3}J_{H,H} = 7.6$  and  ${}^{4}J_{H,H} = 1.0, 1H, H^{5}$ ), 8.39 372 (d,  ${}^{3}J_{H,H} = 7.9$ , 1H,  $H^{8}$ ) and 8.49(d,  ${}^{3}J_{H,H} = 7.9$ , 2H,  $H^{11}$  and  $H^{15}$ ).  ${}^{13}C{}^{1}H$  NMR data: 373  $\delta_{\rm C} = 44.0[^2 J_{\rm C,Pt} = 47.2, Me({\rm dmso})], 44.6[^2 J_{\rm C,Pt} = 55.4, Me({\rm dmso})], 66.9({\rm O}Me), 122.0(C^8),$ 374  $122.7(C^9)$ ,  $127.1(C^5)$ ,  $128.6(C^{14})$ ,  $129.8(C^{12})$ ,  $133.6(C^6)$ ,  $133.7(C^4)$ ,  $133.9(C^7)$ , 375  $134.1(C^{11}), 134.6(C^{15}), 139.4(C^{13}), 151.4(C^3), 152.6(C^{10}) \text{ and } 168.7(C^2).$  <sup>195</sup>Pt{<sup>1</sup>H} NMR 376 data:  $\delta_{Pt} = -2965$ . For **3b**: Anal. calc. for C<sub>17</sub>H<sub>18</sub>Cl<sub>2</sub>N<sub>2</sub>O<sub>2</sub>PtSCH<sub>2</sub>Cl<sub>2</sub>: C, 32.49, H 3.03, N 377 4.21 and S 4.82. Found: C 32.6, H 3.15, N 4.3 and S 4.9%.  $MS(ESI^+)$ :  $m/z = 603 \{[M]-$ 378  $CH_2Cl_2 + Na\}^+$ . IR (selected data):  $v_{max} = 2904[v(C-H)]$  and 1637[v(>C=N-)] cm<sup>-1</sup>. <sup>1</sup>H 379 NMR data:  $\delta_{\rm H} = 2.51$ [s, J<sub>Pt-H</sub> = 20.2, 3H, Me(dmso)], 3.30[s, <sup>3</sup>J<sub>Pt,H</sub> = 22.0, 3H, Me(dmso)], 380 4.38(s, 3H, OMe), 5.13(s, 2H, CH<sub>2</sub>Cl<sub>2</sub>), 7.42(td,  ${}^{3}J_{H,H} = 7.6$  and  ${}^{4}J_{H,H} = 1.0, 1H, H^{6}$ ), 7.30– 381 7.70(br. m, 3H,  $H^{12}$ ,  $H^{13}$  and  $H^{14}$ ), 7.65(td,  ${}^{3}J_{H,H} = 7.6$  and  ${}^{4}J_{H,H} = 1.0$ , 1H,  $H^{7}$ ), 8.15(d, 382

<sup>3</sup>J<sub>H,H</sub> = 7.6 and <sup>4</sup>J<sub>H,H</sub> = 1.0, 1H, 
$$H^5$$
), 8.38(d, <sup>3</sup>J<sub>H,H</sub> = 7.6, 1H,  $H^8$ ) and 8.48(dd, <sup>3</sup>J<sub>H,H</sub> = 8.0  
and <sup>4</sup>J<sub>H,H</sub> = 1.0, 2H,  $H^{11}$  and  $H^{15}$ ). <sup>13</sup>C{<sup>1</sup>H} NMR data:  $\delta_{\rm C}$  = 44.6[<sup>2</sup>J<sub>C</sub>-Pt = 56.0,  
*Me*(dmso)], 45.0[<sup>2</sup>J<sub>C</sub>-Pt = 47.0, *Me*(dmso)], 66.4(O*Me*), 121.7( $C^9$ ), 121.8( $C^8$ ), 127.5( $C^5$ ),  
128.5( $C^{12}$ ), 128.7( $C^{14}$ ), 132.6( $C^7$ ), 132.9( $C^{15}$ ), 131.6( $C^{13}$ ), 131.7( $C^4$ ), 133.2( $C^6$ ),  
133.5( $C^{11}$ ), 151.1( $C^3$ ), 152.4( $C^{10}$ ) and 169.5( $C^2$ ). <sup>195</sup>Pt{<sup>1</sup>H} NMR data:  $\delta_{\rm Pt}$  = -2959.

#### 389 *4.4. Crystallography*

390 Prismatic crystals of 2a, 2b, 3a and 3b (sizes in Table 3) were obtained by slow evaporation of saturated CH<sub>2</sub>Cl<sub>2</sub> solutions of the compounds at 298 K. A crystal of 2a was 391 selected and mounted on a Enraf-Nonius-CAD4 four circle diffractometer; while crystals of 392 393 2b, 3a and 3b were mounted on a MAR345 diffractometer (with an image plate detector). 394 For 2a, unit cell parameters were determined from automatic centring of 25 reflections in the range  $12^{\circ} < \Theta < 21^{\circ}$  while in the remaining cases these parameters were obtained from 395 3798 (for **2b**), 9034 (for **3a**) or 2922 (for **3b**) reflections in the range  $3^{\circ} < \Theta < 31^{\circ}$ . For all 396 the products the unit cell parameters were refined by least-squares method. The number of 397 398 reflections applying the condition I >  $2\sigma(I)$  was 5255 (for 2a), 4982 (for 2b), 4176 (for 3a) or 5520 (for 3b). For 2a, three reflections were measured every 2 h as orientation and 399 intensity control, and no significant intensity decay was observed. Lorentz-polarization and 400 absorption corrections were made. 401

The structures were solved by direct methods using the SHELXS computer program 402 [31] and refined by full-matrix least squares method with the SHELX97 program [32]. The 403 function minimized was  $\sum w ||Fo|^2 - |Fc|^2|^2$ , where  $w = [\sigma^2(I) + (0.0535P)^2 + 6373P]^{-1}$  (for 404 **2a**),  $w = [\sigma^2(I) + (0.0677P)^2]^{-1}$  (for **2b**),  $w = [\sigma^2(I) + (0.0913P)^2]^{-1}$  (for **3a**) and  $w = [\sigma^2(I) + (0.0913P)^2]^{-1}$ 405  $+(0.06139P)^{2}+1.7329P]^{-1}$  (for **3b**); f, f'and f'' were taken from the bibliography [33]. 406 407 For all compounds, hydrogen atoms were computed and refined, using a riding model, with an isotropic temperature factor equal to 1.2 times the equivalent temperature factor of the 408 409 atom to which it is linked. The final R (on F) factors were 0.033 (for 2a), 0.037 (for 2b), 0.060 (for **3a**) and 0.043 (for **3b**) and  $wR(\text{on }F^2)$  was 0.095, 0.087, 0.167, 0.120 and 0.165 410

- 411 for 2a, 2b, **3a** and **3b**, respectively. Further details concerning the resolution and refinement
- 412 of these crystal structures are presented in Table 3.

# 417 Acknowledgements

418	We are grateful to the Ministerio de Ciencia y Tecnología of Spain and to the
419	Generalitat de Catalunya for financial support (Grants: CTQ2009-11501 and 2009-SGR-
420	1111). One of us (P.K.B.) dedicates this paper in the memory of his late father.
421	
422	
423	
424	
425	
426	
427	
428	

### 429 **References**

- 430 [1] A.R. Katritzky, C.A. Ramsden, E.-F.-V. Scriven, R.J.K. Taylor (Eds.), Comprehensive
  431 Heterocyclic Chemistry III, vol. 3, Elsevier, Oxford, UK, 2008. pp. 1–45 and 353–385.
- G. Wilkinson, R.D. Gillard, J.A. McCleverty (Eds.), Comprehensive Coordination Chemistry,
  the Synthesis, Reactions, Properties and Applications of Coordination Compounds, vol. 1,
  Pergamon Press, Oxford, UK, 1987, p. 38.
- For reviews on intermolecular interactions: (a) P. Metrangolo, F. Meyer, T. Pilati, G. Resnati,
  G. Terraneo, Angew. Chem. Int. Ed. 47 (2008) 6114–6127; (b) B.L. Schottel, H.T. Chifotides,
  K.R. Dunbar, Chem. Soc. Rev. 37 (2008) 68–83; (c) M. Nishio, Y. Umezawa, K. Honda, S.
  Tsuboyama, H. Suezawa, CrystEngCommun. 11 (2009) 1757–1788; (d) J.D. Dunitz, A.
  Gavezzotti, Chem. Soc. Rev. 38 (2009) 2622–2633.
- [4] (a) G.R. Desiraju, T. Steiner, The Weak Hydrogen Bond in Structural Chemistry and Biology,
  Oxford Science Publications, Oxford, UK, 1999. Chapter 2, pp. 29–121 and Chapter 3, pp.
  293–342; (b) J. Bernstein, R.E. Davis, L. Shimoni, N.-L. Chang, Angew. Chem. Int. Ed. 34
  (1995) 1555–1573.
- J.W. Steed, J.L. Atwood (Eds.), Supramolecular Chemistry, second ed., John Wiley & Sons,
  Sussex, UK, 2009.
- 446 [6] (a) Y. Zhou, D. Yan, Chem. Commun. (2009) 1172–1188; (b) G.R. Hanson, P. Jensen, J.
  447 McMurtrie, L. Rintoul, A.S. Micallef, Chem. Eur. J. 15 (2009) 4156–4164.
- (a) B. Rodríguez-Spong, C.P. Price, A. Jayasankar, A.J. Matzger, N. Rodríguez-Hornedo,
  Adv. Drug Deliv. Rev. 56 (2004) 241–274; (b) K. Channon, E.H.C. Bromley, D.N. Woolfson,
  Curr. Opin. Struct. Biol. 18 (2008) 491–498.
- 451 [8] (a) J. Gao, Y-G. Liu, R.A. Zingaro, Chem. Res. Toxicol. 22 (2009) 1705–1712; (b) R. Gust,
  452 W. Beck, G. Jaouen, H. Schoenenberger, Coord. Chem. Rev. 253 (2009) 2742–2759; (c) M.
  453 Coluccia, G. Natile, Anti-Cancer Agents Med. Chem. 7 (2007) 111–123; (d) A.C.F. Caires,
  454 Anti-Cancer Agents Med. Chem. 7 (2007) 484–491; (e) B.A. Teicher, Clin. Cancer Res. 14
  455 (2008) 1610–1617.
- 456 [9] S. Pérez, C. López, A. Caubet, X. Solans, M. Font-Bardía, Eur. J. Inorg. Chem. (2008) 1599–
  457 1612.
- 458 [10] (a) P.C.A. Bruijnincx, P.J. Sadler, Curr. Opin. Chem. Biol. 12 (2008) 197–206; (b) X. Wang,
  459 Z. Guo, Dalton Trans. (2008) 1521–1532; (c) S.H. van Rijt, P.J. Sadler, Drug Discov. Today
  460 14 (2009) 1089–1097.

- 461 [11] (a) W.-Y. Wong, G.-Y. Lu, K.-H. Choi, J.-X. Shi, Macromolecules 35 (2002) 3506–3513; (b)
  462 Y. Kang, J. Lee, D. Song, S. Wang, Dalton Trans. (2003) 3493–3499.
- 463 [12] Recent contributions on this area: (a) C.J. Adams, M.F. Haddow, R.J.I. Hughes, M.A. Kurawa, 464 A.G. Orpen, Dalton 39 (2010) 3714-3724; (b) D.A.K. Vezzu, J.C. Deaton, J.S. Jones, L. 465 Bartolotti, C.F. Harris, A.P. Marchetti, M. Kondakova, R.D. Pike, S. Huo, Inorg. Chem. 49 466 (2010) 5107-5119; (c) E. Budzisz, M. Miernicka, I-P. Lorenz, P. Mayer, E. Balcerczak, U. 467 Krajewska, M. Rozalski, Eur. J. Med. Chem. 45 (2010) 2613–2621; (d) A.S. Abu-Surrah, K.A. 468 Abu Safieh, I.M. Ahmad, M.Y. Abdalla, M.T. Ayoub, A.K. Qaroush, A.M. Abu-Mahtheieh, Eur. J. Med. Chem. 45 (2010) 471–475; (e) G. Gupta, B. Therrien, K.M. Rao, J. Organomet. 469 470 Chem. 695 (2010) 753-759.
- 471 [13] (a) E. von Angerer, H. Birnboeck, M. Kager, A. Maucher, J. Cancer Res. Clinic. Oncol. 118
  472 (1992) 339–343; (b) N.G. Knebel, E. von Angerer, J. Med. Chem. 34 (1991) 2145–2152.
- 473 [14] C. López, A. González, C. Moya, R. Bosque, X. Solans, M. Font-Bardía, J. Organomet. Chem.
  474 693 (2008) 2877–2886.
- 475 [15] J.H. Price, A.N. Williamson, R.F. Schramm, B.B. Wayland, Inorg. Chem. 11 (1972) 1280–
  476 1284.
- 477 [16] T.H. Allen, Acta Crystallogr. Sect. B Struct. Sci. B58 (2002) 380–385.
- 478 [17] (a) Y. Suzaki, T. Taira, K. Osakada, Dalton Trans. (2006) 5345–5351; (b) E. Menozzi, M.
  479 Busi, R. Ramingo, M. Campagnolo, S. Geremia, E. Dalcanale, Chem. Eur. J. 11 (2005) 3136–
  480 3148.
- 481 [18] S.F. Alshahateet, R. Bishop, D.C. Craig, M.L. Scudder, Cryst. Growth Des. 4 (2004) 837–844.
- 482 [19] A. Bondi, J. Phys. Chem. 68 (1964) 441–451.
- 483 [20] (a) V.K. Belsky, V.E. Konovalov, V.Y. Kukushkin, Acta Cryst. Sect. C 47 (1991) 292–294;
- (b) P. Marqués-Gallego, H. den Dulk, J. Brouwer, H. Kooijman, A.L. Spek, O. Roubeau, S.J. Teat,
  J. Reedijk, Inorg. Chem. 47 (2008) 11171–11179.
- 486 [21] S.-W. Lai, Q.K.-W. Chan, N. Zhu, C.-M. Che, Inorg. Chem. 46 (2007) 11003–11016.
- 487 [22] R. Venkateswaran, J.T. Mague, M.S. Balakrishna, Inorg. Chem. 46 (2007) 809–817.
- (a) J.S. Casas, M.V. Castaño, M.S. García-Tasende, E. Rodríguez-Castellón, A. Sánchez, L.M.
  Sanjuán, J. Sordo, Dalton Trans. (2004) 2019–2026; (b) P.M.T. Piggot, L.A. Hall, A.J.P.
  White, D.J. Williams, Inorg. Chim. Acta 357 (2004) 207–212.
- 491 [24] J.S. Owen, J.A. Labinger, J.E. Bercaw, J. Am. Chem. Soc. 126 (2004) 8247–8255.

- 492 [25] (a) B.M. Still, P.G.A. Kumar, J.R. Aldrich-Wright, W.S. Price, Chem. Soc. Rev. 36 (2007)
  493 665–686; (b) C. López, S. Pérez, X. Solans, M. Font-Bardía, T. Calvet, New J. Chem. 34
  494 (2010) 676–685.
- 495 [26] (a) N.M. Ocarino, A. Bozzi, R.D.O. Pereira, N.M. Breyner, V.L. Silva, P. Castanheira, A.M.
  496 Goes, R. Serakides, Biocell 32 (2008) 175–183; (b) G. Robledo, G. Seijo, Gen. Mol. Biol. 31
  497 (2008) 717–724.
- 498 [27] (a) J.A.G. Williams, Chem. Soc. Rev. 38 (2009) 1783–1801; (b) C. Reber, J. Grey, E. Lanthier,
  499 K. Frantzen, Comm. Inorg. Chem. 26 (2005) 233–254.
- [28] (a) I. Eryazici, C.N. Moorefield, G.R. Newkome, Chem. Rev. 108 (2008) 1834–1895; (b)
  J.A.G. Williams, S. Develay, D.L. Rochester, L. Murphy, Coord. Chem. Rev. 252 (2008)
  2596–2611; (c) S. Würtz, F. Glorius, Acc. Chem. Res. 41 (2008) 1523–1533; (d) K.M.-C.
  Wong, V.W.-W. Yam, Coord. Chem. Rev. 251 (2007) 2477–2488; (e) M.J. Katz, K. Sakai,
  D.B. Leznoff, Chem. Soc. Rev. 37 (2008) 1884–1895.
- 505 [29] M. Pojarová, D. Kaufmann, R. Gastpar, T. Nishino, P. Reszka, P.J. Bednarski, E. von Angerer,
  506 Bioorg. Med. Chem. 15 (2007) 7368–7379 (and references therein).
- 507 [30] D.D. Perrin, W.L.F. Armarego, Purification of Laboratory Chemicals, fourth ed., Butterworth,
  508 Heinemann, Oxford, UK, 1997.
- 509 [31] G.M. Sheldrick, SHELXS. A computer program for determination of crystal structures,
  510 University of Göttingen, Germany, 1997.
- 511 [32] G.M. Sheldrick, SHELX97. A computer program for determination of crystal structures,
  512 University of Göttingen, Germany, 1997.
- 513 [33] International Tables of X-Ray Crystallography, vol. IV, Kynoch press, Birmingham, UK,
  514 1974, pp. 99–100 and 149
- 515
- 516
- 517

Table 1. Selected bond lengths, bond angles and other relevant structural parameters for 2a, 

#### **2b**, **3a** and **3b**.

	2a	2b	3a	3b
Bond lengths <sup>a</sup>				
Pt-N(1)	2.050(3)	2.032(3)	1.992(6)	2.003(4)
Pt-Cl(1)	2.2899(13)	2.286(2)	2.286(3)	2.287(2)
Pt—Cl(2)	2.3045(14)	2.293(2)	2.321(2)	2.3101(19)
Pt—S	2.2259(15)	2.2203(15)	2.1991(19)	2.211(17)
C(1)-N(1)	1.443(5)	1.441(5)	1.434(9)	1.415(7)
N(1)-C(8)	1.312(6)	1.324(5)	1.282(9)	1.332(7)
C(7)-N(2)	1.320(6)	1.285(5)	1.362(10)	1.310(8)
N(2)-O(1)	1.364(5)	1.365(5)	1.367(9)	1.403(7)
O(1)-C(9)	1.436(6)	1.434(7)	1.404(13)	1.430(9)
Bond angles <sup>b</sup>				
Cl(1)-Pt-Cl(2)	175.95(5)	177.65(4)	90.07(8)	90.94(7)
Cl(1)-Pt-N(1)	86.91(10)	88.56(11)	176.49(16)	179.21(12)
CI(2)-Pt-N(1)	89.47(10)	89.24(11)	86.66(15)	88.29(13)
N(1)-Pt-S	178.1(10)	175.28(9)	92.70(15)	89.88(13)
C(1)-N(1)-C(8)	109.1(13)	108.0(3)	109.9(6)	108.1(4)
C(7)-N(2)-O(1)	111.1(4)	110.2(4)	107.0(6)	110.9(5)
Torsion angles <sup>b</sup>				
C(7)-N(2)-O(1)-C(9)	178.9(4)	171.8(4)	177.0(5)	179.6(6)
Intramolecular C–H···O contacts				
C(5)-H(5) <sup>a</sup>	0.93	0.93	0.93	0.93
$H(5) \cdots O(1)^a$	2.51	2.55	2.59	2.54
$C(5)-H(5)\cdots O(1)^{b,c}$	111	111	108	111

<sup>b</sup> In degrees.
 <sup>c</sup> Bond angle.

Table 2. Experimental visible-ultraviolet spectroscopic data in CH<sub>2</sub>Cl<sub>2</sub> ( $10^{-4}$  M): wavelengths,  $\lambda_i$  (in nm), the molar extinction coefficients, { $\varepsilon_i$  in mol<sup>-1</sup> dm<sup>2</sup> (in parenthesis)} for the free ligands, their closely related phenyl-indole derivatives {**4a** and **4b** (depicted below)}, *trans*-[Pt{C<sub>6</sub>H<sub>4</sub>-4R<sup>1</sup>-1[C<sub>8</sub>H<sub>4</sub>N-3'-NOMe]}Cl<sub>2</sub>(dmso)] {R<sup>1</sup> = Cl (**2a**) or H (**2b**)} and *cis*-[Pt{C<sub>6</sub>H<sub>4</sub>-4R<sup>1</sup>-1[C<sub>8</sub>H<sub>4</sub>N-3'-NOMe]}Cl<sub>2</sub>(dmso)] {R<sup>1</sup> = Cl (**3a**) or H (**3b**)}.

528

Compound	R	$\lambda_1(\varepsilon_1)$	$\lambda_2(\varepsilon_2)$	$\lambda_3(\varepsilon_3)$		
Free ligands and related derivatives						
1a	Cl	272(26560)	329(3350)	404(2570)		
1b	Н	272(27039)	328(3385)	405(2160)		
4a	Cl	269(21350)	324 sh	394(3020)		
4b	Н	264(21350)	326 sh	385(2507)		
Platinum(II) complexes						
2a <sup>a</sup>	Cl	274(25980)	347(7200)	424 sh(2903)		
2b <sup>a</sup>	Н	272(23940)	347(6910)	435 sh(3260)		
3a	Cl	271(26050)	342(8650)	433 sh(2767)		
3b	Н	269(26950)	345(9740)	428(2650)		
ОН						



 $R^1 = CI (4a) \text{ or } H (4b)$ <sup>a</sup> Additional bands at  $\lambda = 253 (\varepsilon = 20160)$  for 2a and 252 ( $\varepsilon = 18403$ ) for 2b.

529

530

**Table 3**. Crystal data and details of the refinement of the crystal structures of compounds

### **2a**, **2b**, **3a** and **3b**.

	2a	2b	3a	3b
Empirical formula	C17H17Cl3N2O2PtS	C17H18Cl2N2O2PtS	C18H19Cl5N2O2PtS	C18H19Cl4N2O2PtS
Formula weight	614.83	580.38	699.75	664.30
Crystal size/mm $\times$ mm $\times$ mm	$0.17 \times 0.15 \times 0.14$	$0.17\times0.15\times0.14$	0.2  imes 0.1  imes 0.1	0.2  imes 0.1  imes 0.1
T/K	293(2)	293(2)	293(2)	293(2)
λ/Â	0.71073	0.71073	0.71073	0.71073
Crystal system	Monoclinic	Triclinic	Monoclinic	Triclinic
Space group	P21/c	P-1	P2 <sub>1</sub> /c	P-1
a/Â	9.717(5)	7.753(9)	9.679(6)	10.019(5)
b/Å	9.349(3)	9.612(2)	13.692(6)	10.710(4)
c/Å	23.382(8)	13.421(8)	18.065(9)	12.254(4)
α/°	90.0	103.86(3)	90	68.07(2)
β/°	101.993(7)	93.71(7)	91.25(3)	78.10(2)
γl°	90.0	93.63(4)	90	79.65(3)
V/Å <sup>3</sup>	2077.8(14)	965.8(13)	2394(2)	1185.9(8)
Ζ	4	2	4	2
$D_{\rm calc}/{\rm Mg}  imes {\rm m}^{-3}$	1.965	1.996	1.942	1.860
$\mu/\text{mm}^{-1}$	7.253	7.662	6.525	6.471
F(0 0 0)	1176	556	1344	638
$\Theta$ range for data collection/°	From 2.81 to 30.00	From 2.19 to 29.97	From 2.58 to 30.08	From 2.55 to 32.36
N. of reflections collected	5748	5609	15,422	12,011
N. of unique reflections	5748 [R <sub>int</sub> = 0.0638]	$5608 [R_{int} = 0.0186]$	$5035 [R_{int} = 0.0512]$	6369 $[R_{int} = 0.0420]$
Completeness to $\Theta = 30.0^{\circ}$	94.9%	100%	92.6%	96.1%
Absorption correction	Empirical	Empirical	Empirical	Empirical
N. of data	5748	5608	5035	6369
N. of parameters	235	226	262	271
Goodness of fit on $F^2$	1.105	1.116	1.093	1.080
Final R indices $[I > 2\sigma(I)]$	$R_1 = 0.0331, wR_2 = 0.0930$	$R_1 = 0.0368, wR_2 \ 0.0857$	$R_1 = 0.0602, wR_2 0.1611$	$R_1 = 0.0433, wR_2 0.1166$
Final R indices (all data)	$R_1 = 0.0400, wR_2 \ 0.0964$	$R_1 = 0.0393, wR_2 \ 0.0871$	$R_1 = 0.0705, wR_2 0.1672$	$R_1 = 0.0498, wR_2 0.1206$
Largest diff. peak and hole/e Å <sup>3</sup>	0.932, -0.847	0.923, -0.854	0.960, -0.732	0.702, -0.851

#### 536 Figures Captions

- 537 Scheme 1. (i) Cis-[PtCl<sub>2</sub>(dmso)<sub>2</sub>] {molar ratios Pt(II): (1a or 1b) = 1:1} in MeOH under 538 reflux. (ii) 2 h. (iii) 8 h. (iv) SiO<sub>2</sub>-column chromatography.
- Figure 1. ORTEP plot of *trans*-[Pt{C6H4-4Cl-1-[C8H4N-3'-NOMe]}Cl2(dmso)] (2a). Hydrogen atoms have been omitted for clarity.
- 541 Figure. 2. ORTEP plot of *trans*-[Pt{C<sub>6</sub>H<sub>5</sub>-1-[C<sub>8</sub>H<sub>4</sub>N-3'-NOMe]}Cl<sub>2</sub>(dmso)] (2b).
- 542 Hydrogen atoms have been omitted for clarity.
- **Figure 3.** Assembly of two vicinal molecules of *trans*-[Pt{C6H4-4Cl-1-[C8H4N-3'-NOMe]}Cl<sub>2</sub>(dmso)] (**2a**) by C-H···N interactions (in blue) forming eight membered rings (**a**) and simplified view of the connectivity of these units by C-H···O(dmso) interactions (in red) (**b**), the C-H···Cl intermolecular interactions are not shown for clarity. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)
- **Figure 4**. Schematic views of  $C-H \cdot \cdot \cdot Cl$  intermolecular interactions (in gray) between molecules of *trans*-[Pt{C<sub>6</sub>H<sub>5</sub>-1-[C<sub>8</sub>H<sub>4</sub>N-3'-NOMe]}Cl<sub>2</sub>(dmso)] (**2b**), forming chains and of the eight-membered rings resulting from  $C-H \cdot \cdot \cdot O$  contacts (in red) between dmso ligands of two different and parallel chains. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)
- **Figure 5.** ORTEP plot of *cis*-[Pt{C<sub>6</sub>H<sub>4</sub>-4Cl-1-[C<sub>8</sub>H<sub>4</sub>N-3'-NOMe]}Cl<sub>2</sub>(dmso)]·CH<sub>2</sub>Cl<sub>2</sub>
- 554 (**3a**). Hydrogen atoms and the molecule of CH<sub>2</sub>Cl<sub>2</sub> and have been omitted for clarity.
- Figure 6. ORTEP plot of cis-[Pt{C<sub>6</sub>H<sub>5</sub>-1-[C<sub>8</sub>H<sub>4</sub>N-3'-NOMe]}Cl<sub>2</sub>(dmso)]·CH<sub>2</sub>Cl<sub>2</sub> (**3b**).
- 556 Hydrogen atoms and the molecule of CH<sub>2</sub>Cl<sub>2</sub> and have been omitted for clarity
- 557 Figure 7. Schematic view of the cooperative assembly of two molecules of *cis*-[Pt{C<sub>6</sub>H<sub>4</sub>-
- 4Cl-1-[C<sub>8</sub>H<sub>4</sub>N-3'-NOMe] Cl<sub>2</sub>(dmso)] and two of CH<sub>2</sub>Cl<sub>2</sub> in the crystals of **3a** by C-H··
- $\cdot$  O (in red) and C–H···Cl (in gray) interactions. (For interpretation of the references to
- color in this figure legend, the reader is referred to the web version of this article.)
- 561 Figure 8. Schematic view of the relative arrangement of the molecules of *cis*-[Pt{C<sub>6</sub>H<sub>5</sub>-1-
- 562  $[C_8H_4N-3'-NOMe]$  Cl<sub>2</sub>(dmso)] in **3b** (a) by cooperative bifurcated C-H···O interactions

- between dmso units and the assembly of the resulting dimers by  $C-H \cdot \cdot Cl(1)$  contacts (b).
- **Figure 9**. Excitation and emission spectra of 1b in CH<sub>2</sub>Cl<sub>2</sub>,  $5 \times 10^{-5}$  M (a) and emission
- 565 spectra of **1b** in CH<sub>2</sub>Cl<sub>2</sub>,  $10^{-3}$  M, (**b**) at 298 K.
- 566 Figure 10. Excitation and emission spectra of 1a in CH .  $2Cl_2$ , 5 x  $10^{-5}$  M (a) and emission
- 567 spectra of **1a** in CH<sub>2</sub>Cl<sub>2</sub>,  $10^{-3}$  M, (**b**) at 298 K.

**Scheme 1.** 







































Figure 10 



