Electronic Supplementary Material (ESI) for Physical Chemistry Chemical Physics.

How fine-tuned for energy transfer is the environmental noise produced by proteins around biological chromophores?

Kirsten Claridge, Daniele Padula,* Alessandro Troisi*

Department of Chemistry, University of Liverpool, Liverpool L69 7ZD, U.K.

E-mail: DP dpadula@liverpool.ac.uk, AT a.troisi@liverpool.ac.uk

Supporting Information

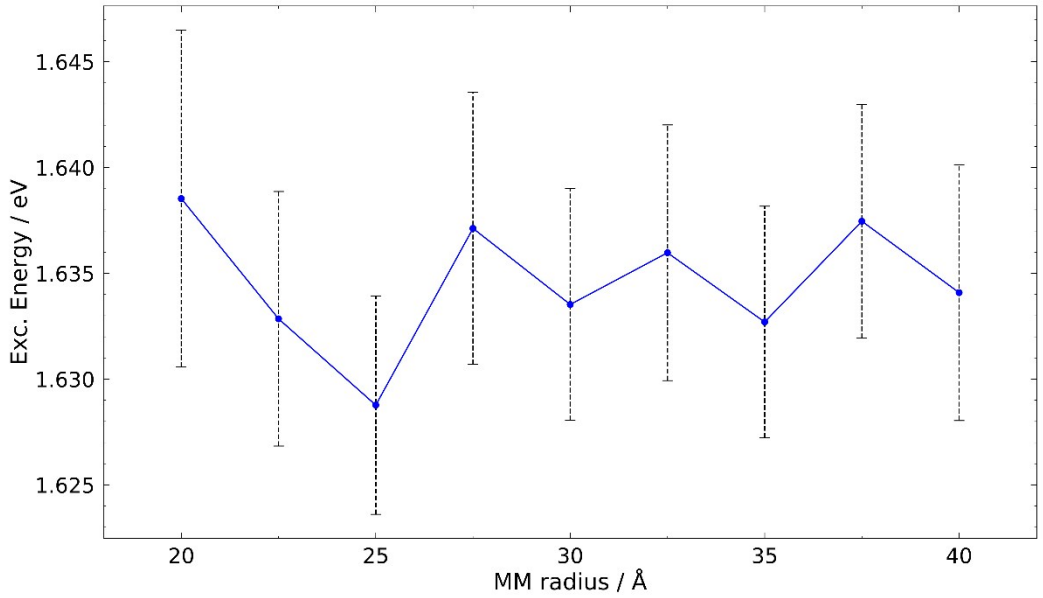

Fig. S1: QM/MM ωB97X-D/6-31G* excitation energy as a function of the MM radius around the chromophore. Excitation energy computed as an average over 50 points (error bars represent the fluctuation over the 50 points).

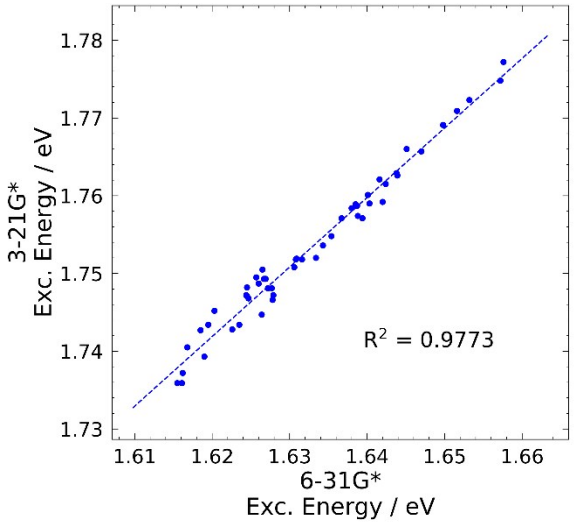

Fig. S2: correlation between QM/MM ωB97X-D/6-31G* and QM/MM ωB97X-D/3-21G* excitation energies (slope = 0.89 ± 0.02).

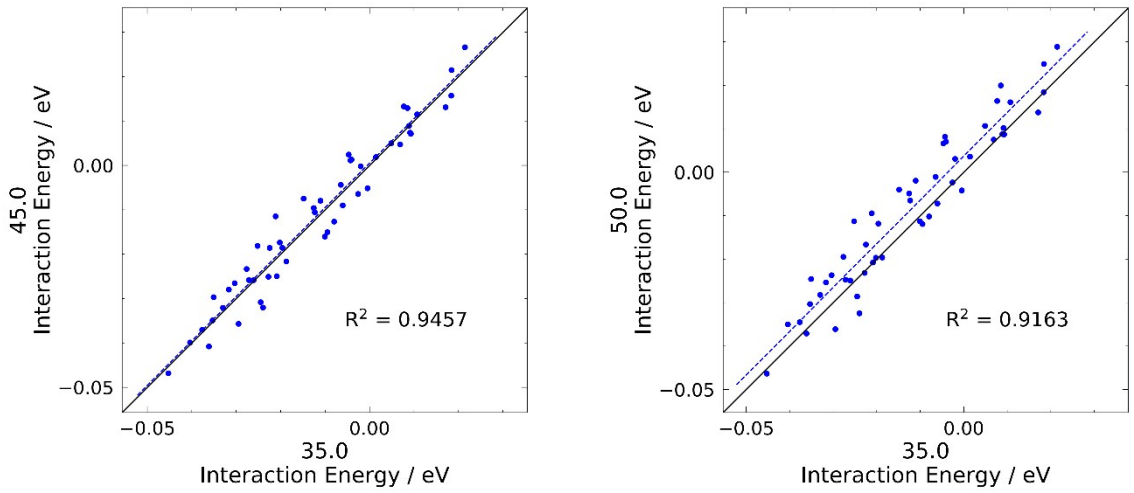

Fig. S3: correlation between coulombic interaction energies between the chromophore and the environment with various MM radiuses.

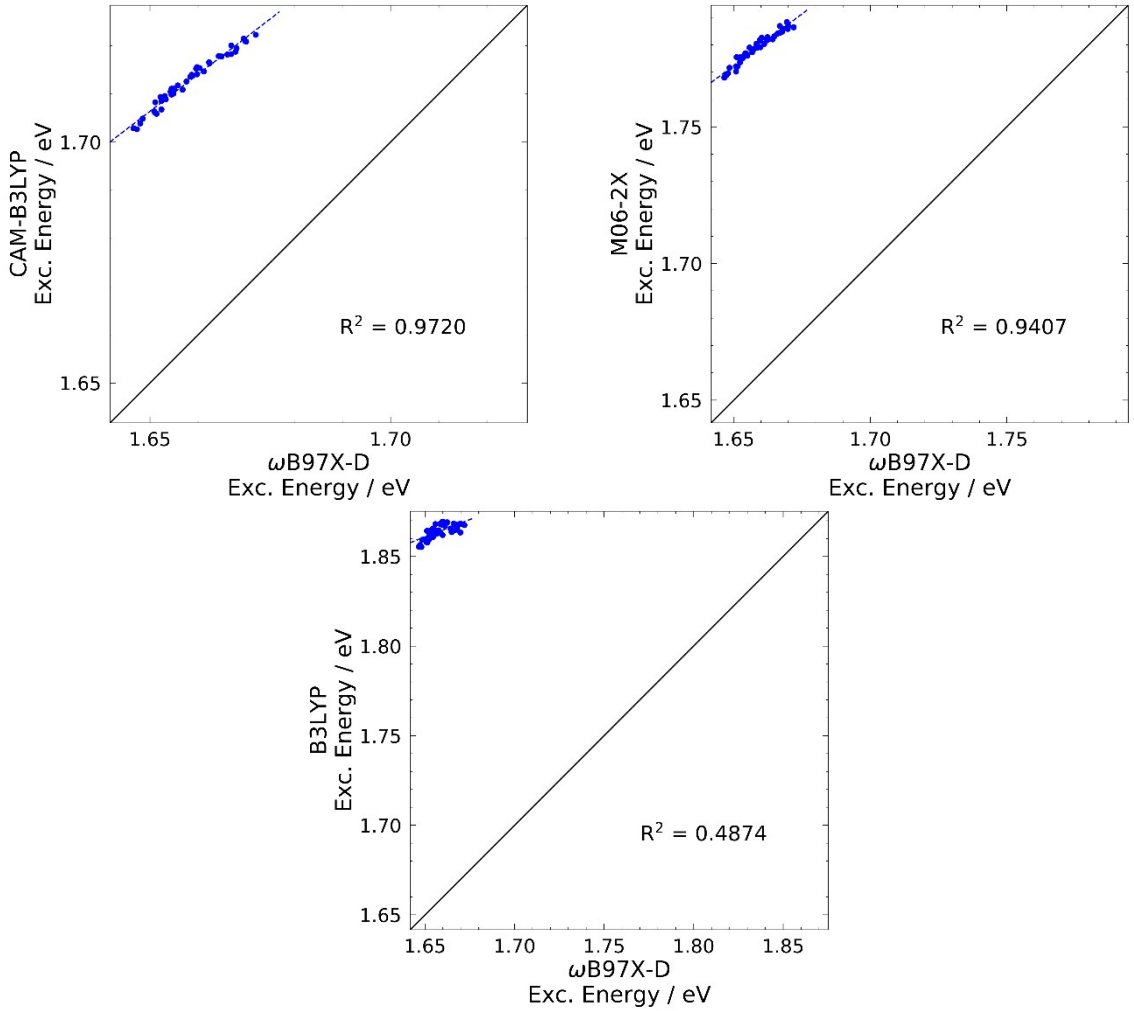

Fig. S4: correlation between QM/MM 6-31G* energies computed with various functionals.

The 10 largest correlation coefficients for each chromophore, the fluctuation of the coulombic interaction energy (σ_E), the names of the interacting atoms, an assignment of the interaction, Chromophore (C), Solvent (S) or Protein (P) and the distance between interacting atoms (d) with its fluctuation (σ_d), where available.

Table S1: Correlation analysis of residues for BCLs.

Residue	r	σ_E (eV)	Interaction	Class	d (Å)	σ_d (Å)
			BCL 367			
SOL19499	0.395	3.29E-04	HW2-O1A	S	1.68	0.15
THR162	0.328	1.10E-04	HG1-CMA	P	3.66	0.41
SOL10024	0.314	9.65E-05	HW-OG	S	2.47	0.58
SER221	0.291	1.37E-04	HG-OBB	P	1.83	0.24
HIS111	0.279	2.24E-04	NE2-MG	P	2.09	0.08
SOL49632	0.249	1.26E-05	HWs-OWs	S	-	-
SOL32676	0.243	4.39E-05	HW-OD1/O/OW	S	-	-
SOL25062	0.237	3.44E-05	HWs-OWs	S	-	-
ASN206	0.237	9.16E-06	OD1-HW+ND2H-OW	P	-	-
SOL38635	0.236	1.85E-05	OW-HN/HWs	S	-	-
			BCL 368			
SOL20272	0.373	2.89E-04	OW-MG	S	1.95	0.05
SOL16680	0.335	3.21E-04	HW1-ND	S	2.19	0.28
SER73	0.318	2.17E-04	HG-OBB	P	1.77	0.19
BCL367	0.234	1.47E-04	-	C	-	-
SOL20275	0.221	2.36E-04	HWs-CHB	S	1.62	0.16
BCL372	0.218	1.46E-05	-	C	-	-
SOL37375	0.218	3.15E-05	HWs-OWs	S	-	-
MET103	0.212	2.00E-05	O-HN	P	2.02	0.16
SOL39517	0.206	1.45E-04	HWs-O1D/O1A	S	-	-
LYS81	0.202	8.97E-05	O-HWs	P	-	-
			BCL 369			
SOL19513	0.369	1.82E-04	HW-ND	S	2.76	0.52
SOL19542	0.353	4.84E-04	OW-MG	S	2.19	0.14
BCL370	0.248	9.24E-05	-	C	-	-
PHE307	0.236	4.55E-05	Phenyl-CMC	P	-	-
GLU101	0.227	2.18E-06	O-HWs	P	-	-
SOL19530	0.222	1.13E-04	HWs-OWs	S	-	-
SOL19558	0.220	2.38E-04	HWs-Os	S	-	-
SOL51900	0.177	2.88E-05	HWs-ND	S	2.63	0.55
SOL14934	0.172	2.39E-05	OWs-HWs	S	-	-
HIS298	0.171	2.42E-04	NE2-MG	P	2.12	0.09
			BCL 370			
SOL26496	0.485	4.18E-04	HW-NE2	S	2.75	0.51
BCL371	0.410	1.84E-04	-	C	-	-
HIS290	0.243	2.32E-04	NE2-MG	P	2.01	0.06
PRO294	0.220	5.47E-05	HN-O	P	2.09	0.18
TYR364	0.181	5.70E-06	HN-O + HH-OG	P	-	-
ASP48	0.179	6.89E-06	ODs-HWs + HN-O	P	-	-
TYR16	0.172	1.37E-04	HH-OBB	P	1.71	0.19
VAL352	0.150	7.58E-05	O-HN	P	2.09	0.16

ASN289	0.146	2.44E-05	OWs-HWs	P	-	-
BCL373	0.141	3.27E-05	-	C	-	-
			BCL 371			
SOL26411	0.306	1.87E-04	HW-OG	S	2.30	0.50
GLU255	0.288	2.46E-05	O-HN/HWs	P	-	-
PRO244	0.274	1.46E-04	O-HBB	P	2.67	0.22
LEU242	0.269	1.48E-04	O-MG	P	1.99	0.09
SER245	0.255	7.19E-05	O-HW	P	1.95	0.18
ARG96	0.250	1.23E-04	HHs-OWs	P	-	-
GLU85	0.237	3.85E-05	OEs -HWs	P	-	-
SOL49632	0.212	7.64E-05	HWs-OWs	S	-	-
LYS247	0.197	4.71E-05	O-HWs	P	-	-
BCL372	0.197	1.33E-04	-	C	-	-
			BCL 372			
SOL26466	0.385	1.94E-04	HWs-OWs	S	-	-
HIS146	0.375	2.83E-04	NE2-MG	P	2.06	0.08
TRP184	0.278	1.27E-04	HE1-OBB	P	1.97	0.21
SOL24901	0.228	9.02E-06	HWs-OWs	S	-	-
LYS56	0.203	6.53E-06	HWs-OWs	S	-	-
SER201	0.197	2.97E-05	HN-Os + HG1-OWs	P	-	-
ARG199	0.186	2.18E-05	HHs-OWs/ODs	P	-	-
PHE225	0.185	5.60E-05	O-HN	P	1.92	0.13
LYS247	0.181	2.04E-05	HZ-OD1	P	1.82	0.25
SER98	0.176	7.93E-05	HG1/HN-O	P	-	-
			BCL 373			
SOL27138	0.398	2.66E-04	HW-OE1	S	1.82	0.14
SOL27010	0.324	7.49E-05	HWs-OWs	S	-	-
BCL369	0.318	1.92E-04	-	C	-	-
SOL20275	0.311	5.82E-05	HWs-OWs	S	-	-
SOL19499	0.280	1.29E-04	HWs-OWs	S	-	-
ALA189	0.270	6.18E-05	O-NH	P		
SOL19526	0.249	1.83E-05	HWs-OWs	S	-	-
HIS297	0.238	1.36E-04	ND1-MG	P	2.15	0.07
SOL20286	0.236	4.12E-05	HWs-OWs	S	-	-
SOL26450	0.225	1.22E-04	HW-OBB	S	1.84	0.24
			BCL 400			
SOL32299	0.424	3.28E-04	HW-CHB	S	2.11	0.45
SOL34010	0.301	1.61E-04	HW-HMB	S	3.56	0.61
SOL20922	0.286	3.84E-04	HWs-OWs	S	-	-
TYR124	0.217	1.33E-04	O-MG	P	1.98	0.08
SOL5540	0.212	1.13E-04	HWs-OWs	S	-	-
SOL39842	0.210	3.37E-05	HWs-OWs	S	-	-
SOL20307	0.194	3.34E-05	HWs-OD1/OWs	S	-	-
THR166	0.188	1.06E-04	HG1/HN-O	P	-	-
SOL39022	0.187	4.16E-05	HWs-OWs	S	-	-
SOL8492	0.180	3.36E-05	HWs-OWs	S	-	-

Table S2: Correlation analysis of residues for CLAs.

Residue	r	σ_E (eV)	Interaction	Class	d (Å)	σ_d (Å)
			CLA 1			
ALA34	0.539	1.95E-04	O-HE1	P	1.84	0.13
ALA33	0.459	1.17E-04	O-HN	P	1.89	0.14
SOL10184	0.340	1.46E-04	HWs-OWs	S	-	-
SOL17152	0.237	4.46E-05	HWs-OWs	S	-	-
TRP151	0.229	7.52E-05	O-HWs + HE1-O	P	-	-
GLY153	0.228	1.12E-06	O-HWs + HN-OWs	P	-	-
GLU85	0.184	3.47E-06	OEs-HWs + HN-OWs	P	-	-
SOL23264	0.178	2.97E-05	HWs-OWs	S	-	-
ASN91	0.177	1.21E-05	O/OD1-HWs + Hs-OWs	P	-	-
PHE40	0.168	4.03E-05	pi-stacking	P	-	-
			CLA 2			
ALA33	0.452	9.99E-05	HN-O	P	2.04	0.19
SOL21499	0.434	6.29E-05	HWs-O	S	-	-
ASN36	0.425	2.75E-05	O -HWs + H-OWs	P	-	-
PRO39	0.424	1.68E-05	O-HW	P	2.11	0.53
SOL33283	0.420	1.63E-05	HWs-O	S	-	-
SOL28386	0.419	1.55E-05	HWs-OWs	S	-	-
PHE40	0.394	5.08E-05	O-HWs	P	-	-
SOL36758	0.390	1.25E-05	HWs-OWs	S	-	-
SOL23262	0.364	8.33E-05	HWs-OE1	S	-	-
SOL35595	0.352	1.32E-05	HWs-OWs	S	-	-
			CLA 3			
ALA34	0.612	2.06E-04	O-HE1	P	1.93	0.17
ALA33	0.516	1.15E-04	O-HN	P	1.91	0.15
SOL20477	0.256	4.28E-06	HWs-OWs	S	-	-
TRP151	0.242	1.31E-06	HE1-O + HN-OWs	P	-	-
GLN53	0.242	1.43E-04	OBD-HE21	P	1.80	0.34
SOL6708	0.219	1.29E-04	HWs-OWs	S	-	-
SOL21943	0.217	4.15E-05	HWs-OWs	S	-	-
SOL12421	0.208	9.50E-06	HWs-OWs	S	-	-
SOL22197	0.200	1.07E-04	HW-O1D	S	1.79	0.19
PRO88	0.193	2.95E-05	O-HW	P	-	-
			CLA 4			
THR48	0.447	1.28E-04	HG1-OBD	P	2.25	0.42
SOL23254	0.361	4.54E-04	HWs-OWs	S	-	-
GLN47	0.268	5.62E-05	O-HBA2	P	3.25	0.31
SOL32487	0.211	1.35E-04	HWs-OWs	S	-	-
ALA33	0.208	1.07E-04	HN-OWs	P	-	-
SOL22243	0.199	5.34E-05	HWs-OE1/O	S	-	-
GLY28	0.192	1.32E-05	HN-OWs + O-HE21	P	-	-
SOL16127	0.174	7.60E-06	HWs-OWs	S	-	-
SOL19783	0.158	1.71E-05	HWs-OWs	S	-	-
ALA34	0.156	1.79E-04	O-HE1	P	1.86	0.12

Table S3: Correlation analysis of residues for CLB.

Residue	r	σ_E (eV)	Interaction	Class	d (Å)	σ_d (Å)
			CLB 1			
ALA33	0.430	1.31E-04	HN-O	P	2.04	0.16
ALA34	0.403	2.06E-04	O-HE1	P	1.86	0.12
SOL16413	0.359	2.29E-04	HW-CAB	S	2.44	0.60
GLY153	0.293	1.70E-05	O-HWs	P	-	-
LEU152	0.283	1.60E-05	O-HWs	P	-	-
PRO32	0.264	1.36E-04	O-Mg	P	1.96	0.07
SOL17261	0.236	8.35E-05	HWs-OBD	S	2.12	0.50
SOL23877	0.185	5.70E-06	HWs-OWs	S	-	-
THR48	0.172	9.37E-05	HN/HG1-O	P	-	-
SOL8351	0.170	5.62E-06	HWs-OWs	S	-	-
			CLB 2			
SOL13389	0.369	2.04E-04	HW-C2D	S	1.98	0.21
SOL2821	0.304	4.56E-05	HWs-OWs	S	-	-
ALA33	0.296	1.21E-04	HN-O	P	1.99	0.16
ALA34	0.286	1.92E-04	O-HE1	P	1.96	0.16
GLN53	0.286	1.12E-04	O-HG1 + OE1-HWs	P	-	-
THR48	0.264	1.11E-04	HG1/HN-O + O-HWs	P	-	-
SOL381	0.240	1.99E-05	HWs-OWs	S	-	-
CYS90	0.189	2.14E-05	O-HWs	P	-	-
LEU49	0.188	1.76E-05	HN-O1A	P	1.78	0.16
PRO32	0.183	1.27E-04	O-Mg	P	1.91	0.07
			CLB 3			
GLU85	0.282	1.64E-05	O-HW	P	5.89	0.97
SOL6715	0.271	2.55E-05	HWs-O/OWs	S	-	-
SOL38322	0.270	4.97E-05	HW-OAC	S	1.75	0.23
LEU152	0.265	4.26E-05	O-HWs	P	-	-
GLU85	0.254	1.95E-05	OEs-HWs + HN-OWs	P	-	-
ALA154	0.251	4.88E-05	O-HWs + HN-O	P	-	-
SOL31151	0.236	1.79E-05	HWs-OWs	P	-	-
CHL4	0.234	9.36E-05	-	C	-	-
CYS90	0.227	1.49E-06	HN-OWs + O-HWs	P	-	-
SOL4743	0.225	5.52E-05	OWs-HWs	S	-	-
			CLB 4			
SOL1780	0.582	6.21E-04	HWs-OWs	S	-	-
SOL4246	0.347	3.46E-05	HWs-OWs	S	-	-
LEU152	0.336	1.57E-05	O-HWs	P	-	-
LEU152	0.336	1.57E-05	O-HWs + HN-O	P	-	-
ASN36	0.292	1.19E-05	Hs-OWs + OD1-HWs	P	-	-
LEU93	0.288	1.14E-05	O-HWs	P	-	-
SOL6448	0.283	8.03E-06	HWs-OWs	S	-	-
SOL36798	0.242	9.27E-06	HWs-OWs	S	-	-
SOL2002	0.242	1.34E-05	HWs-OWs	S	-	-
PRO155	0.241	2.67E-05	O-HG1 + O-HN	P	-	-

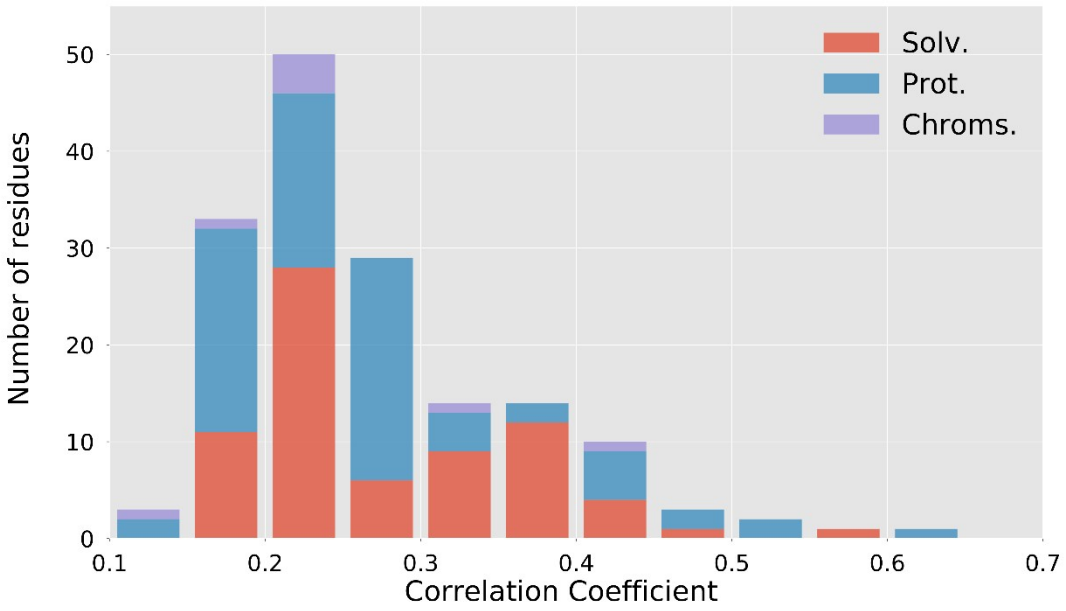

Fig. S5: distribution and classification of the correlation coefficients reported in Tables S1-3.

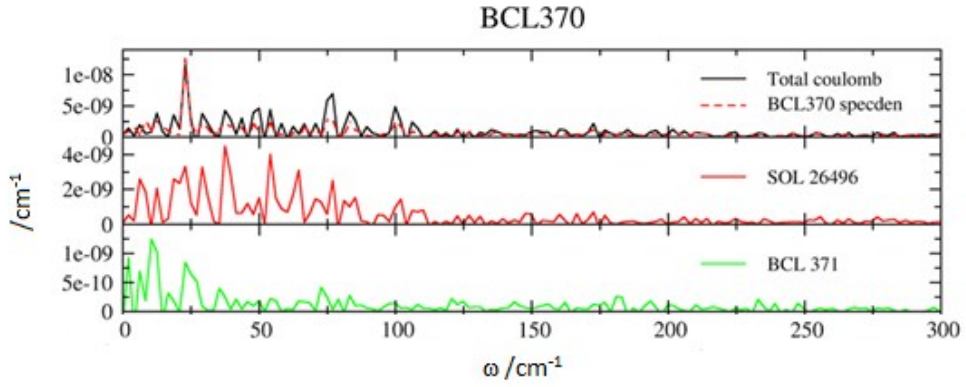

Fig. S6: FT of coulombic interaction energies of most correlated residues for BCL 370

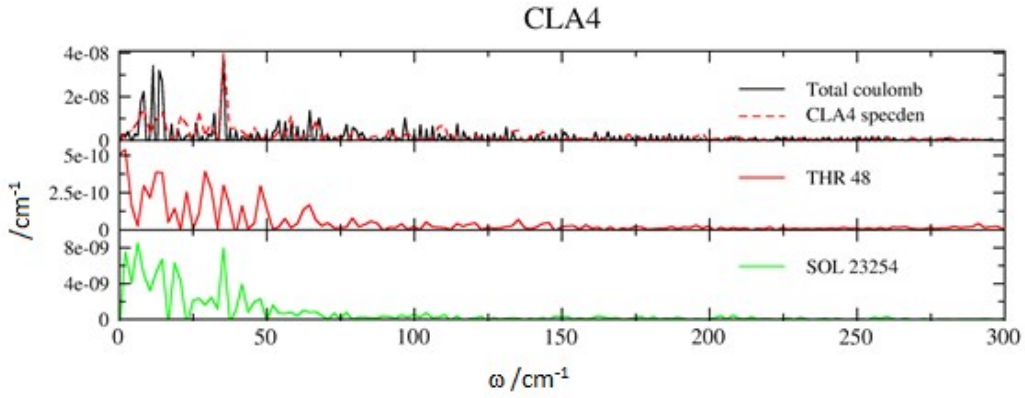

Fig. S7: FT of coulombic interaction energies of most correlated residues for CLA 4

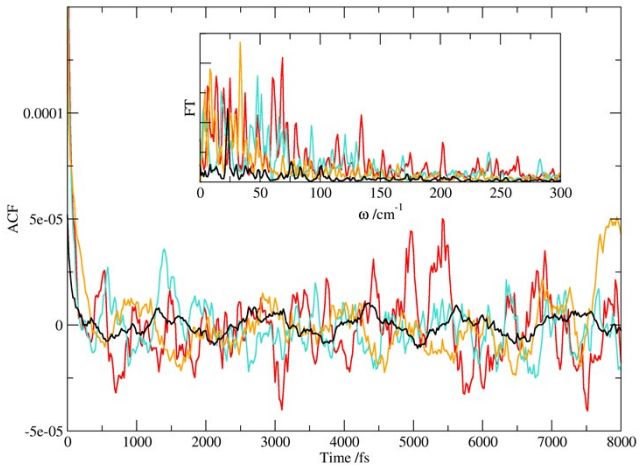

Fig. S8: ACFs and FTs for BCL 370 obtained for different 16ps time windows, separated by 3ns.

Table S4: average number and type of residues in a 15 Å shell from the chromophore.

	Chrom	Prot	Solv	Tot
BCL367	1.97	60.19	76.47	138.63
BCL368	3.00	59.19	83.31	145.50
BCL369	2.00	69.28	66.83	138.10
BCL370	2.00	70.94	46.35	119.29
BCL371	2.00	57.05	81.28	140.33
BCL372	1.00	64.15	40.58	105.72
BCL373	4.00	58.97	54.53	117.50
BCL400	1.00	51.44	177.41	229.85
CLA1	1.00	71.69	55.39	128.08
CLA2	1.00	70.33	49.68	121.01
CLA3	1.00	70.37	48.87	120.24
CLA4	1.00	69.50	65.24	135.74
CLB1	1.00	73.00	46.44	120.44
CLB2	1.00	70.91	63.94	135.85
CLB3	1.00	73.08	53.09	127.17
CLB4	1.00	69.82	64.92	135.74

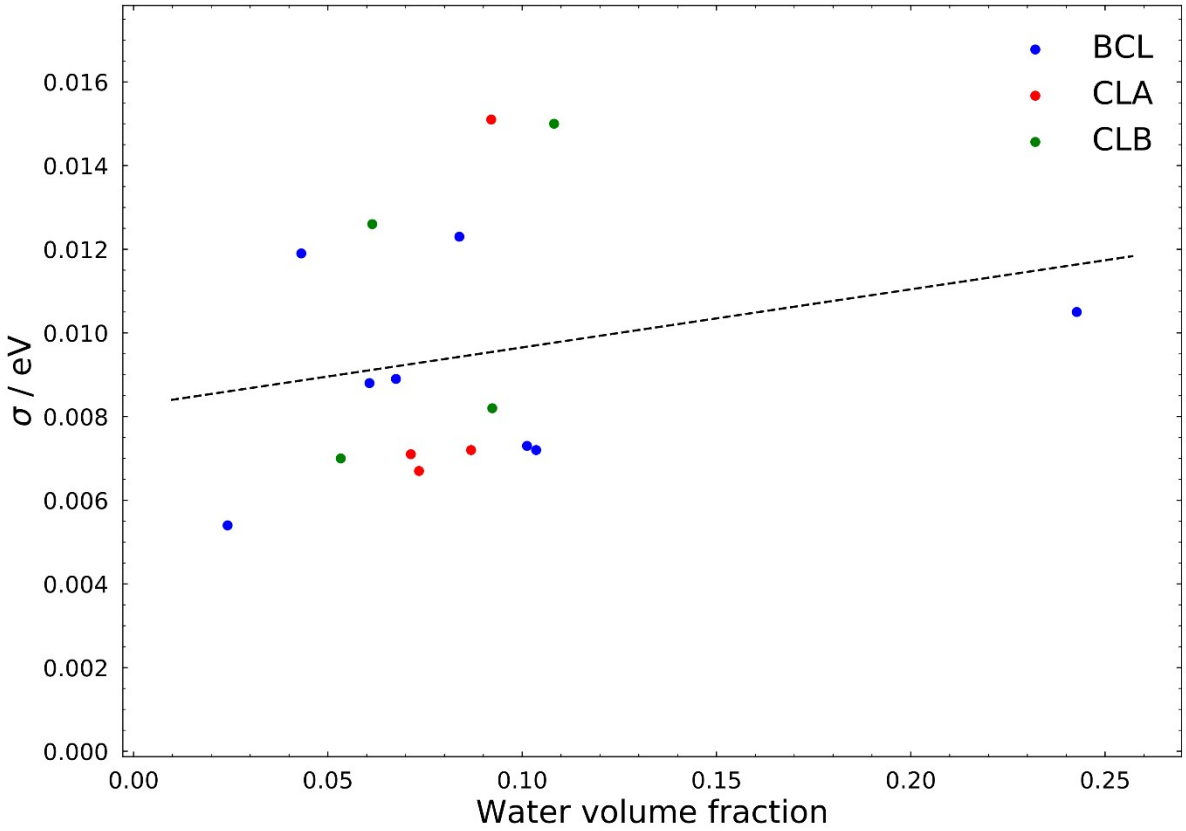

Fig. S9: Correlation between the fraction of water volume in a 10 Å radius from the chromophore and the fluctuation of the excitation energy along the MD trajectory.

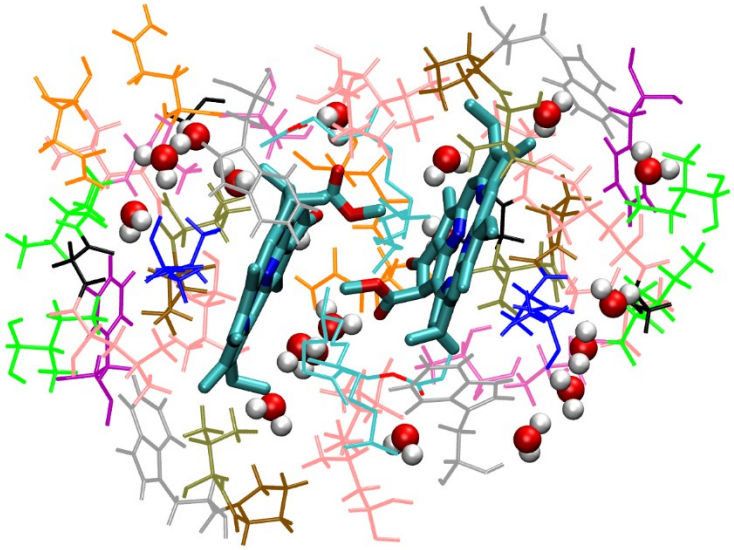

Fig. S10: CLA1 and CLA2 pair; symmetric protein environment but different solvent.

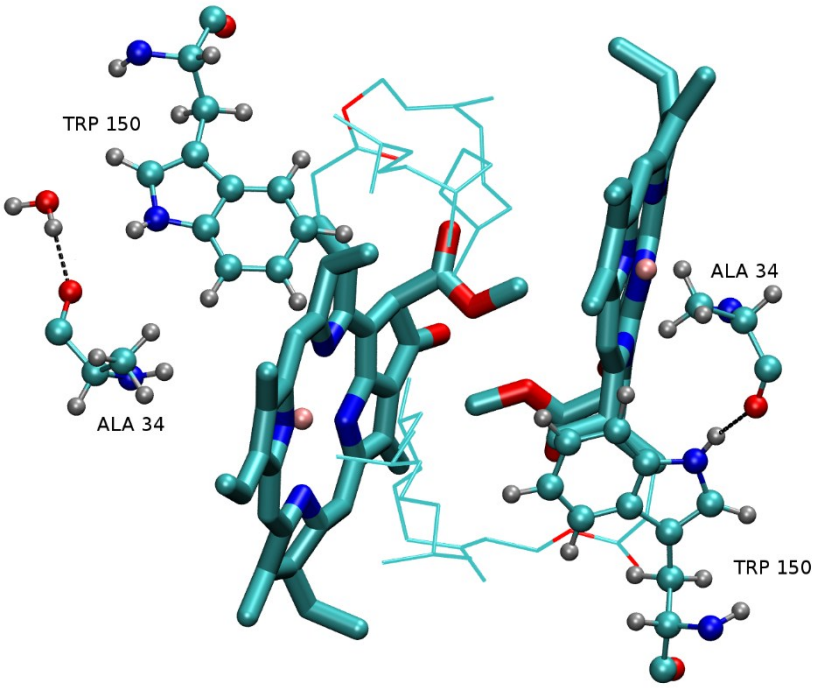

Fig. S11: Example consequence of differing surrounding solvent: ALA 34 – TRP 150 interaction.

The average interatomic separation and its fluctuation, between oxygen of ALA 34 and hydrogen of TRP 150 for different solvent environment, and ALA 34 oxygen and solvent hydrogen.

Table S5: average number and type of residues in a 15 Å shell from the chromophore

Interaction	Avg. interatomic sep. /Å	σ /Å
ALA O – TRP H without SOL	1.92	0.16
ALA O – TRP H with SOL	3.33	0.38
ALA O – SOL H	2.08	0.28

The interatomic separation is greater and there is more fluctuation of this residue when there is solvent near the ALA 34 residue.