Supplementary Information

**Molecular Basis for the Adaptive Evolution of Environment Sensing by H-NS Proteins**

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Includes:

1. Supplementary file 1A – 1F
2. Supplementary References

**Supplementary file 1A**. The sequence similarity matrix of H-NSST, H-NSEA, H-NSBA, and H-NSIL

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | H-NSST | H-NSEA | H-NSBA | H-NSIL |
| H-NSST | 100 | 89.55 | 62.22 | 40.74 |
| H-NSEA | 89.55 | 100 | 62.69 | 39.85 |
| H-NSBA | 62.22 | 62.69 | 100 | 33.58 |
| H-NSIL | 40.74 | 39.85 | 33.58 | 100 |

**Supplementary file 1B.** Summary of reported H-NS simulations (MD = unbiased molecular dynamics simulation; US = umbrella sampling simulations). The CHARMM36 force field (1) with TIP3P water model was used. Total simulation length = 5.7 μs.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Simulation | Num. of atoms | Box  (nm3) | [NaCl]  (mol/L) | T(K) | Time (ns) | Note |  |
| **H-NSST tetramer** | | | | | | Each tetramer model (illustrated in **Fig. 1** of the main text) contains two full-length H-NS monomers (PDB templates: 3NR7 and 2L93) and two partial monomers of site1, to mimic the full-length H-NS monomers in the polymeric state. Each construct was simulated with 2 replicas. |  |
| MD | 102,953 | 13910 | 0.15 | 293 | 200×2 |  |
| MD | 102,101 | 13910 | 0.50 | 293 | 200×2 |  |
| MD | 102,953 | 13910 | 0.15 | 313 | 200×2 |  |
| **H-NEA tetramer** | | | | | |  |
| MD | 100,055 | 13910 | 0.15 | 293 | 200×2 |  |
| MD | 99,227 | 13910 | 0.50 | 293 | 200×2 |  |
| MD | 100,055 | 13910 | 0.15 | 313 | 200×2 |  |
| **H-NSBA tetramer** | | | | | |  |
| MD | 104,551 | 13910 | 0.15 | 293 | 200×2 |  |
| MD | 103,691 | 13910 | 0.50 | 293 | 200×2 |  |
| MD | 104,551 | 13910 | 0.15 | 313 | 200×2 |  |
| **H-NSIL tetramer** | | | | | |  |
| MD | 104,733 | 13910 | 0.15 | 293 | 200×2 |  |
| MD | 103,896 | 13910 | 0.50 | 293 | 200×2 |  |
| MD | 104,733 | 13910 | 0.15 | 313 | 200×2 |  |
| **H-NSST site2 dimer** | | | | | |  |  |
| US | 45,920 | 1366 | 0.15 | 293 | 54×80 | Each site2 dimer model contains two site2 monomers (residues 50-82). We used 80 windows (at an interval of ~0.3 Å) to sample the pathway of dimer dissociation along the direction of increasing center of mass (COM) distance at the constraint of 1.2  kcal/mol/Å2, each umbrella window was simulated for 54 ns. |  |
| US | 45,524 | 1366 | 0.50 | 293 | 54×80 |  |
| US | 45,920 | 1366 | 0.15 | 313 | 54×80 |  |
| **H-NEA site2 dimer** | | | | | |  |
| US | 45,863 | 1366 | 0.15 | 293 | 54×80 |  |
| US | 45,467 | 1366 | 0.50 | 293 | 54×80 |  |
| US | 45,863 | 1366 | 0.15 | 313 | 54×80 |  |
| **H-NSBA site2 dimer** | | | | | |  |
| US | 45,968 | 1366 | 0.15 | 293 | 54×80 |  |
| US | 45,572 | 1366 | 0.50 | 293 | 54×80 |  |
| US | 45,968 | 1366 | 0.15 | 313 | 54×80 |  |
| **H-NSIL site2 dimer** | | | | | |  |
| US | 45,899 | 1366 | 0.15 | 293 | 54×80 |  |
| US | 45,503 | 1366 | 0.50 | 293 | 54×80 |  |
| US | 45,899 | 1366 | 0.15 | 313 | 54×80 |  |

**Computational Data analysis:** All the data analyses were carried out in GROMACS, VMD Tcl scripts, and in-house Python programs. In particular, root-mean-square fluctuations (RMSF), root-mean-square deviation (RMSD), salt-bridge interaction, polar interaction, and hydrophobic interaction were analyzed in VMD (2). For salt-bridges, the O and N atoms in the charged residues (Arg, His, Lys, Asp, and Glu) were used with a distance cut-off of 4.5 Å. For the polar interaction, the atoms in the side chains with the partial charge cutoff (> 0.3 unit for a polar contact) were used with a distance cutoff of 4.5 Å. The cut-off for classifying hydrophobic interactions was 6.0 Å between the C atoms of the hydrophobic residues. The relative percentage (*P*) of hydrophobic contacts is defined as **Eq. 1**.

(Eq. 1)

N is the total number of frames, *Cn* is the number of hydrophobic contacts at frame *n*, and *M* is the largest value in the series of *Cn*. The PMFs were determined using the Weighted Histogram Analysis Method (WHAM) (3) implemented in GROMACS. All the visualization was performed with python, VMD, Pymol (Schrödinger, Inc.), and Maestro (Schrödinger, Inc.).

**Supplementary file 1C.** The average RMSF of each helical region in H-NS site1/site2 at different conditions. The average of the last 10 ns out of a total of 200 ns of both replicas were used.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | [NaCl] (mol/L) | T(K) | | α1 (Å) | α2 (Å) | α3N (Å) | α3C (Å) | α4 (Å) |
| **H-NSST** | | | | | | | | |
| 1 | 0.15 | | 293 | 3.5 ± 1.2 | 2.3 ± 0.4 | 4.5 ± 1.0 | 3.3 ± 0.9 | 5.1 ± 1.8 |
| 2 | 0.50 | | 293 | 3.3 ± 1.3 | 2.3 ± 0.3 | 4.6 ± 1.3 | 4.7 ± 1.3 | 5.8 ± 1.7 |
| 3 | 0.15 | | 313 | 3.7 ± 1.5 | 2.4 ± 0.3 | 4.9 ± 1.2 | 3.9 ± 0.8 | 5.0 ± 1.3 |
| **H-NSEA** | | | | | | | | |
| 4 | 0.15 | | 293 | 4.7 ± 2.0 | 2.3 ± 0.2 | 4.3 ± 1.1 | 4.0 ± 1.9 | 14.6 ± 4.3 |
| 5 | 0.50 | | 293 | 6.2 ± 2.3 | 2.4 ± 0.3 | 4.7 ± 1.2 | 5.3 ± 1.9 | 14.6 ± 4.7 |
| 6 | 0.15 | | 313 | 5.3 ± 1.8 | 2.6 ± 0.3 | 5.0 ± 1.3 | 4.7 ± 1.3 | 15.7 ± 3.1 |
| **H-NSBA** | | | | | | | | |
| 7 | 0.15 | | 293 | 2.6 ± 0.8 | 2.4 ± 0.5 | 5.7 ± 3.1 | 4.5 ± 1.9 | 9.1 ± 4.9 |
| 8 | 0.50 | | 293 | 2.7 ± 0.9 | 2.3 ± 0.3 | 5.4 ± 1.7 | 4.4 ± 1.2 | 8.5 ± 5.9 |
| 9 | 0.15 | | 313 | 2.5 ± 0.8 | 2.6 ± 0.4 | 4.9 ± 1.4 | 5.3 ± 1.9 | 6.1 ± 1.7 |
| **H-NSIL** | | | | | | | | |
| 10 | 0.15 | | 293 | 1.5 ± 0.4 | 2.2 ± 0.2 | 4.6 ± 1.9 | 4.7 ± 1.7 | 15.8 ± 7.3 |
| 11 | 0.50 | | 293 | 1.5 ± 0.3 | 2.3 ± 0.2 | 5.1 ± 1.4 | 4.2 ± 1.2 | 8.1 ± 2.4 |
| 12 | 0.15 | | 313 | 1.6 ± 0.3 | 2.5 ± 0.3 | 5.7 ± 1.8 | 4.2 ± 1.0 | 10.2 ± 2.9 |

**Supplementary file 1D**. Free energy prediction of mutations by prediction tools

|  |  |  |
| --- | --- | --- |
| Site 1 Mutations | Maestro | PremPS |
|  | ΔΔG(kcal/mol) | ΔΔG (kcal/mol) |
|  |  |  |
| L5A | 1.20 | 0.81 |
| L5K | 1.04 | 0.7 |
| L5R | 1.01 | 0.75 |
| L5E | 0.82 | 1.0 |
| L5D | 1.24 | 1.01 |
| L5Q | 0.71 | 0.86 |
| L5N | 1.21 | 0.89 |
|  |  |  |
| L8A | 1.16 | 1.03 |
| L8K | 1.04 | 1.53 |
| L8R | 1.22 | 1.5 |
| L8E | 0.68 | 1.65 |
| L8D | 1.69 | 1.72 |
| L8Q | 0.70 | 1.3 |
| L8N | 1.43 | 1.72 |
|  |  |  |
| I11A | 0.39 | 0.81 |
| I11K | 0.86 | 0.69 |
| I11R | 1.03 | 0.99 |
| I11E | -0.13 | 1.15 |
| I11D | 0.04 | 1.11 |
| I11Q | 0.20 | 0.9 |
| I11N | 0.25 | 1.11 |
|  |  |  |
| R12A | -0.01 | -0.12 |
| R12K | 0.18 | -0.09 |
| R12R | - | - |
| R12E | -0.31 | -0.14 |
| R12D | -0.21 | -0.05 |
| R12Q | -0.14 | -0.15 |
| R12N | -0.05 | -0.02 |
|  |  |  |
| L14A | 1.26 | 0.84 |
| L14K | 1.28 | 1.24 |
| L14R | 1.22 | 0.97 |
| L14E | 0.93 | 1.67 |
| L14D | 2.17 | 1.68 |
| L14Q | 0.65 | 1.25 |
| L14N | 1.70 | 1.66 |
|  |  |  |
| L23A | 0.53 | 1.18 |
| L23K | 1.23 | 1.35 |
| L23R | 1.11 | 1.33 |
| L23E | -0.03 | 1.51 |
| L23D | 0.10 | 1.68 |
| L23Q | 0.17 | 1.31 |
| L23N | 0.50 | 1.44 |
|  |  |  |
| L26A | 1.63 | 2.16 |
| L26K | 1.82 | 2.34 |
| L26R | 1.31 | 2.32 |
| L26E | 1.58 | 2.41 |
| L26D | 2.24 | 2.53 |
| L26Q | 0.73 | 2.28 |
| L26N | 2.35 | 2.51 |
|  |  |  |
| E28A | 1.03 | 0.25 |
| E28K | 2.00 | 0.31 |
| E28R | 1.62 | 0.33 |
| E28E | - | - |
| E28D | 0.07 | 0.54 |
| E28Q | 0.36 | 0.37 |
| E28N | 0.75 | 0.35 |
|  |  |  |
| L30A | 0.69 | 1.12 |
| L30K | 1.12 | 1.16 |
| L30R | 1.31 | 1.00 |
| L30E | 0.40 | 1.39 |
| L30D | 1.28 | 1.59 |
| L30Q | 0.33 | 1.04 |
| L30N | 0.75 | 1.35 |
|  |  |  |
| L33A | 1.80 | 2.03 |
| L33K | 2.06 | 2.19 |
| L33R | 1.65 | 2.19 |
| L33E | 2.13 | 2.28 |
| L33D | 2.80 | 2.45 |
| L33Q | 1.30 | 2.18 |
| L33N | 2.89 | 2.37 |
|  |  |  |
| V36A | 0.77 | 1.69 |
| V36K | 0.92 | 2.3 |
| V36R | 0.89 | 2.25 |
| V36E | 0.17 | 2.32 |
| V36D | 1.27 | 2.45 |
| V36Q | 0.60 | 2.31 |
| V36N | 0.95 | 2.36 |
|  |  |  |
| E39A | 1.04 | 0.36 |
| E39K | 2.16 | 0.43 |
| E39R | 1.53 | 0.49 |
| E39E | - | - |
| E39D | 0.16 | 0.43 |
| E39Q | 0.09 | 0.44 |
| E39N | 0.78 | 0.48 |

**Supplementary file 1E.** Comparison of prediction tools and free energy calculations

|  |  |  |  |
| --- | --- | --- | --- |
| Site 1  Mutations | Maestro | PremPS | Free Energy Calculations |
|  | ΔΔG(kcal/mol) | ΔΔG (kcal/mol) | ΔΔG(kcal/mol) |
| L23K | 1.23 | 1.35 | 12.1 |
| L23R | 1.11 | 1.33 | 14.5 |
| L23E | -0.03 | 1.51 | 2.6 |
| L23D | 0.10 | 1.68 | 4.3 |
| L23Q | 0.17 | 1.31 | 4.6 |
| L23N | 0.50 | 1.44 | 2.6 |
| L26A | 1.63 | 2.16 | 8.42 |
| L26K | 1.82 | 2.34 | 6.56 |
| L26R | 1.31 | 2.32 | 6.88 |
| L26E | 1.58 | 2.41 | 7.92 |
| L26D | 2.24 | 2.53 | 0.58 |
| L26Q | 0.73 | 2.28 | 10.56 |
| L26N | 2.35 | 2.51 | 1.93 |

**Supplementary file 1F.** Statistics of conservative charged contacts in MD simulations (sidechain N-O distances in Å, averaged over the last 50 ns of two simulation replicas).

|  |  |  |  |
| --- | --- | --- | --- |
|  | 293 K, 0.15 M NaCl | 313 K, 0.15 M NaCl | 293 K, 0.50 M NaCl |
| **E52-R56** |  |  |  |
| H-NSST | 7.2 ± 2.7 | 7.5 ± 3.0 | 7.0 ± 2.8 |
| H-NSEA | 6.9 ± 2.8 | 7.3 ± 2.9 | 7.5 ± 3.0 |
| H-NSBA | N/A due to E52Q | | |
| H-NSIL | N/A due to E52A | | |
| **R/K54/53-D71’** |  |  |  |
| H-NSST | 7.4 ± 1.9 | 8.1 ± 1.9 | 10.3 ± 2.2 |
| H-NSEA | 9.2 ± 1.8 | 8.9 ± 2.3 | 8.7 ± 2.1 |
| H-NSBA | N/A due to D71N  N/A due to R54Q | | |
| H-NSIL |
| **R/K54/53-E74’** |  |  |  |
| H-NSST | 4.6 ± 1.2 | 7.9 ± 4.1 | 7.8 ± 3.2 |
| H-NSEA | 6.9 ± 3.8 | 9.1 ± 4.4 | 5.0 ± 3.3 |
| H-NSBA | 8.5 ± 4.8 | 5.6 ± 2.2 | 8.4 ± 2.5 |
| H-NSIL | 5.2 ± 2.0 | 8.4 ± 5.2 | 8.4 ± 3.52 |
| **K57/56-D67’/68’** |  |  |  |
| H-NSST | 3.9 ± 1.3 | 3.7 ± 1.1 | 4.1 ± 1.8 |
| H-NSEA | 3.8 ± 1.4 | 4.3 ± 1.5 | 3.6 ± 1.3 |
| H-NSBA | 4.9 ± 2.9 | 3.5 ± 1.1 | 3.5 ± 0.9 |
| H-NSIL |  | N/A due to D57I |  |
| **R62-E/D63** |  |  |  |
| H-NSST | 10.0 ± 2.3 | 7.0 ± 2.4 | 9.8 ± 2.1 |
| H-NSEA | 8.7 ± 2.0 | 8.6 ± 2.2 | 9.6 ± 2.1 |
| H-NSBA | 9.7 ± 1.8 | 7.1 ± 2.9 | 7.9 ± 2.5 |
| H-NSIL | N/A due to E62S | | |

**References**

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