# What did the Hiwi do besides making coffee?

## Vibrational energy transport in the WW loop

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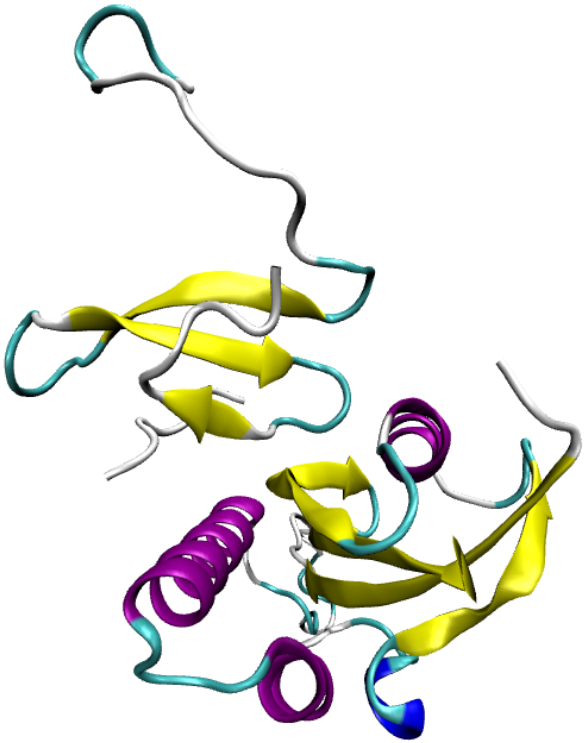
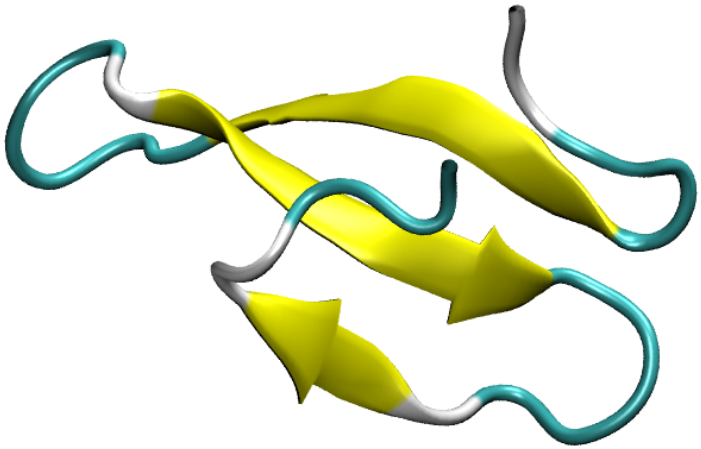
# WW loop



- found in peptidil-prolyl isomerase (Pin1)
- 34 residues
- 3 anti-parallel $\beta$-sheets

# WW loop



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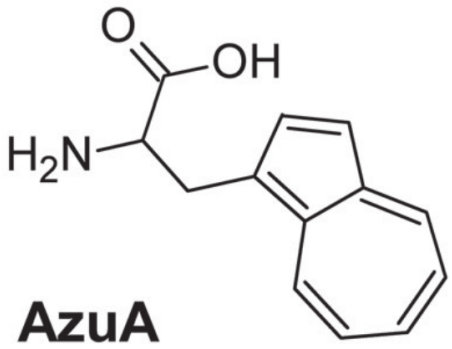
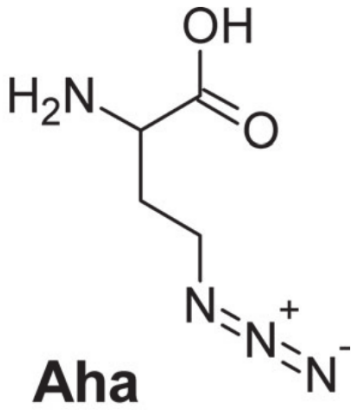
# Heater and "thermometer"

Experimental monitoring of VET needs a pump-probe-pair




**AzuA**

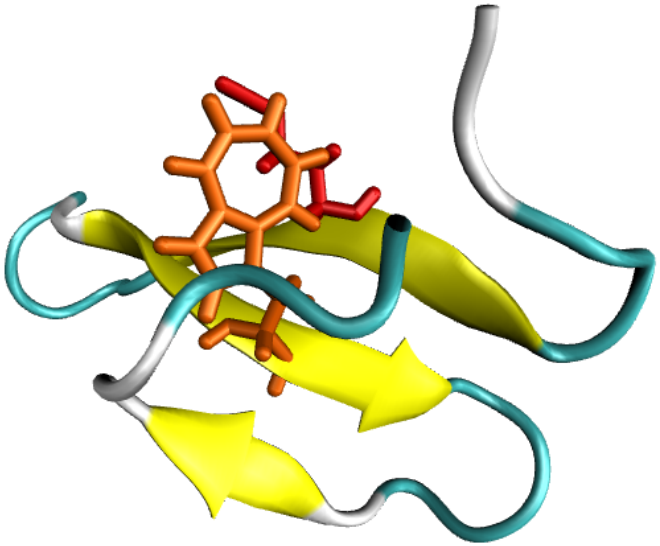
- excitable at 600 nm
- full vibrational decay on sub-picosecond time scale




**Aha**

- monitored at 2098 $cm^{-1}$
- sensitive to low frequency modes

# Manipulated WW loop



- experimentally synthesized mutants
  - 8 AHA / 19 AZU
  - 8 AHA / 29 AZU
  - 17 AHA / 19 AZU
  - 26 AHA / 29 AZU
- simulated: 8 AHA / 19 AZU

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# Simulation details

- 200 conformations from 100 K equilibrium simulation
- cool down to 10 K
- couple chromophore of AZU to 910 K and freeze rest of protein
- 100 ps NEQ simulation with $\Delta t = 0.2$ fs

$\rightarrow$ kinetic energies averaged over 200 trajectories

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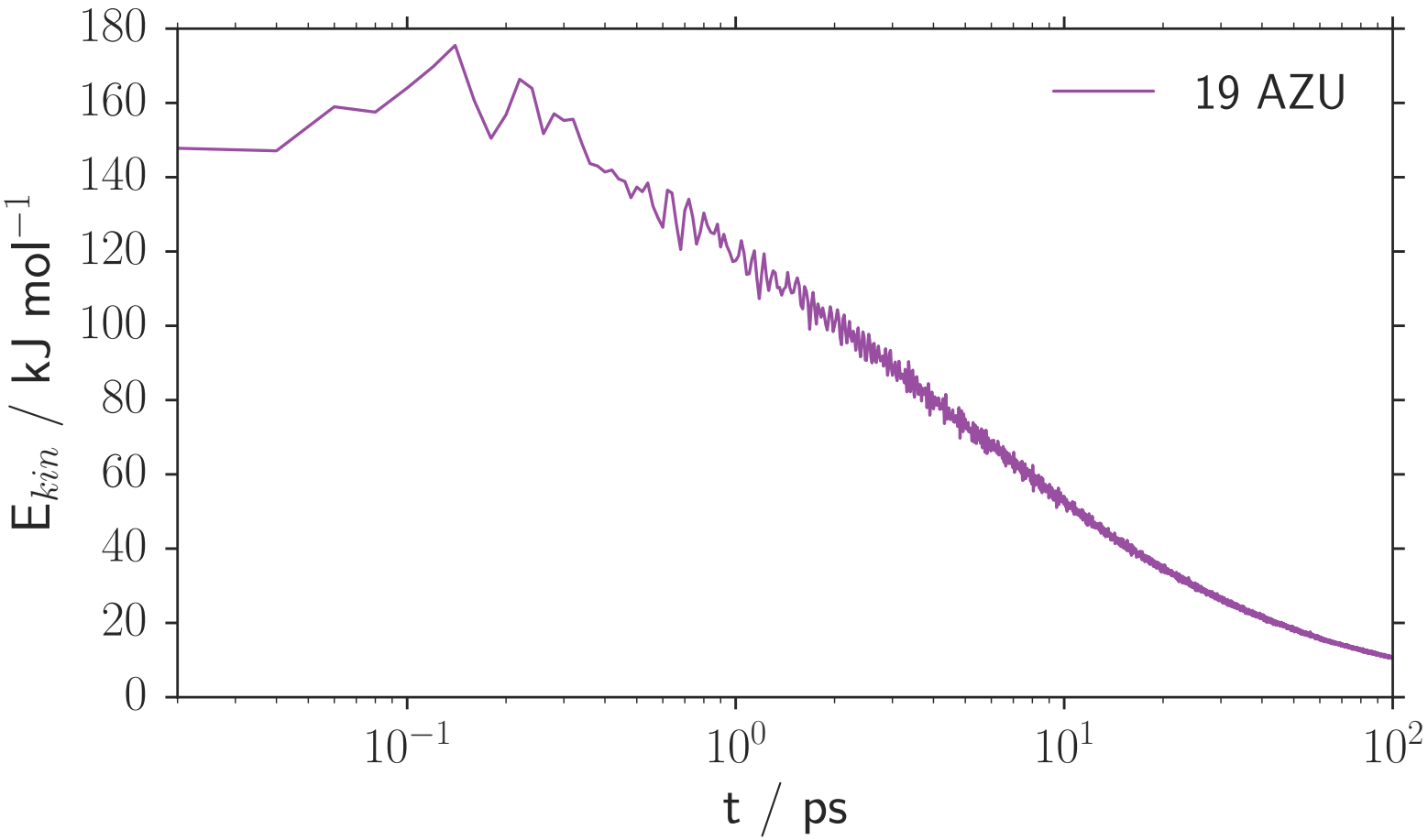
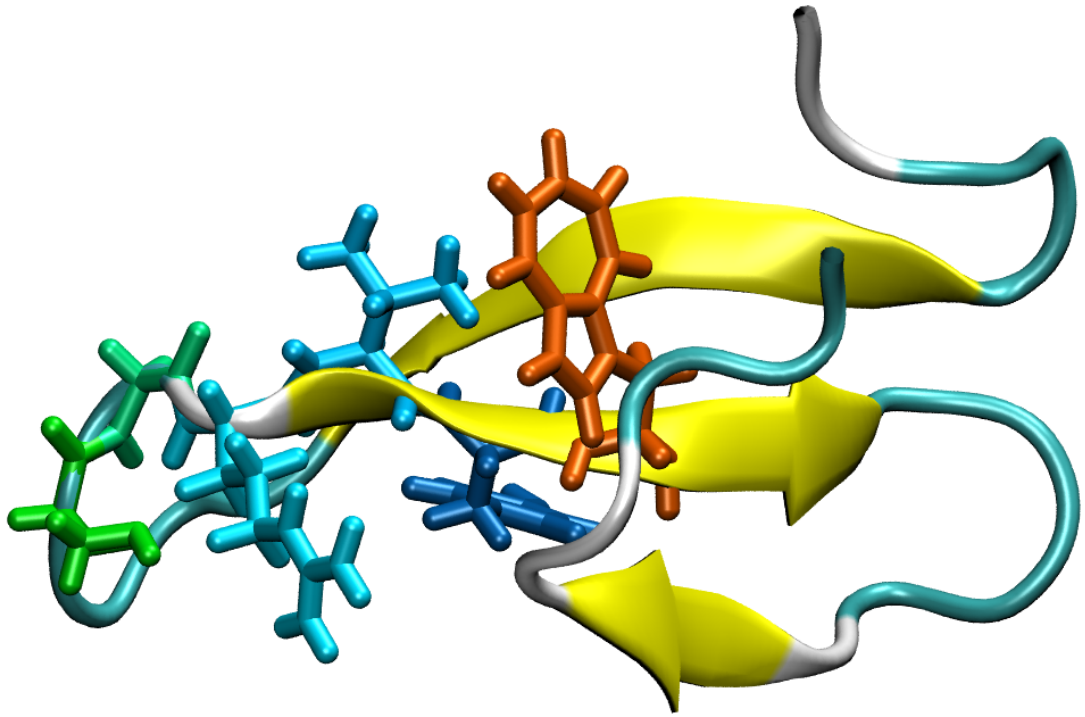
# Heater

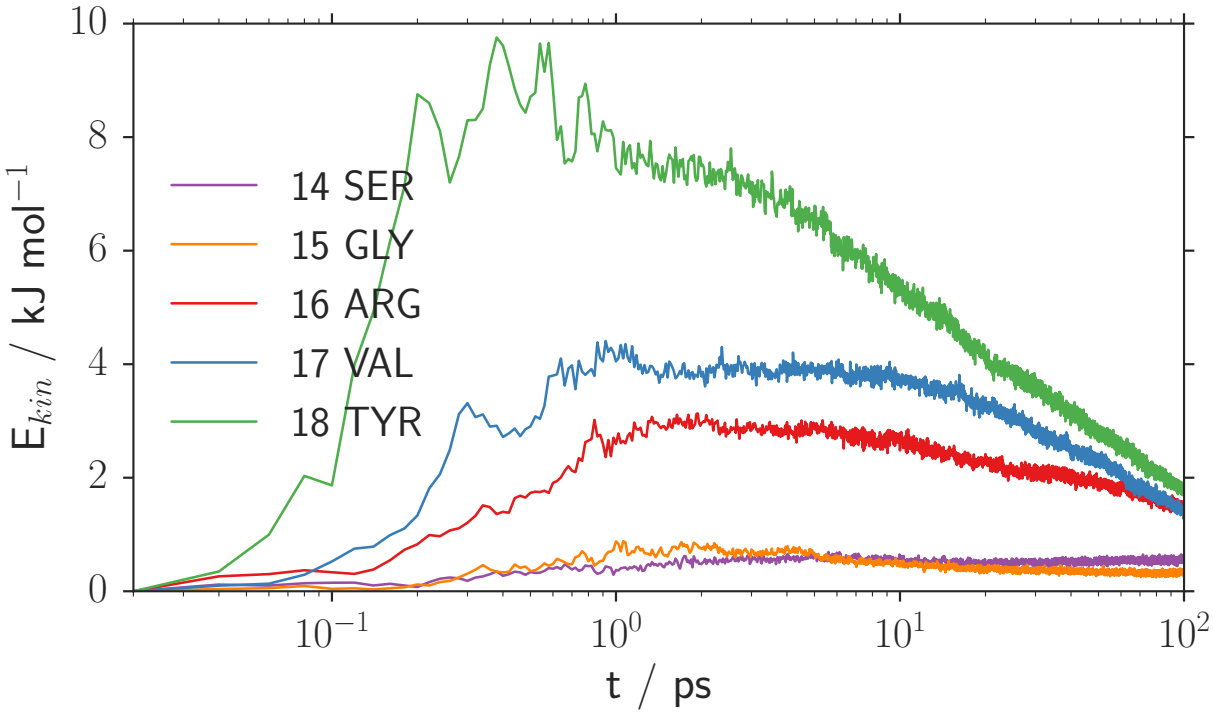



$\rightarrow$ fitted decay time $\tau$ = 10.3 ps

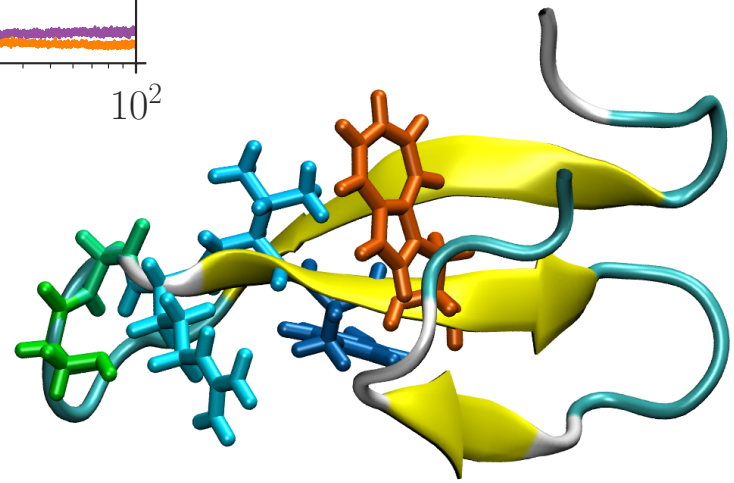
# Upstream neighbours



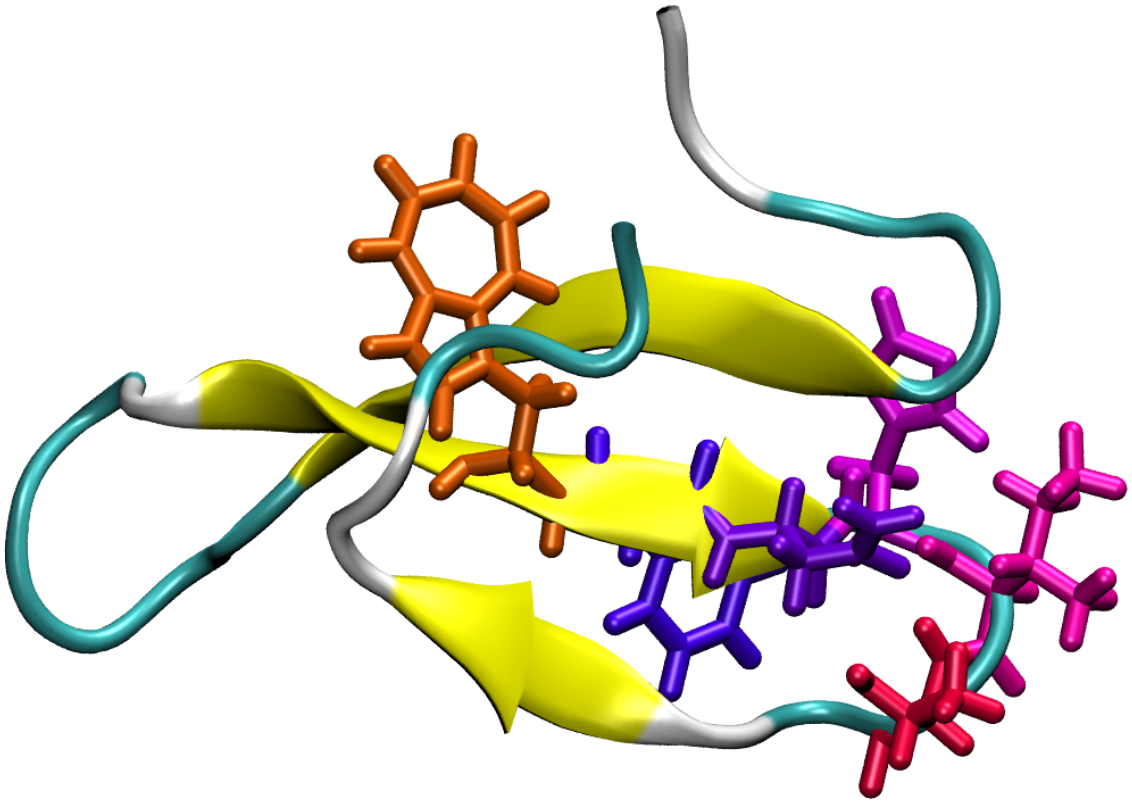
# Upstream neighbours



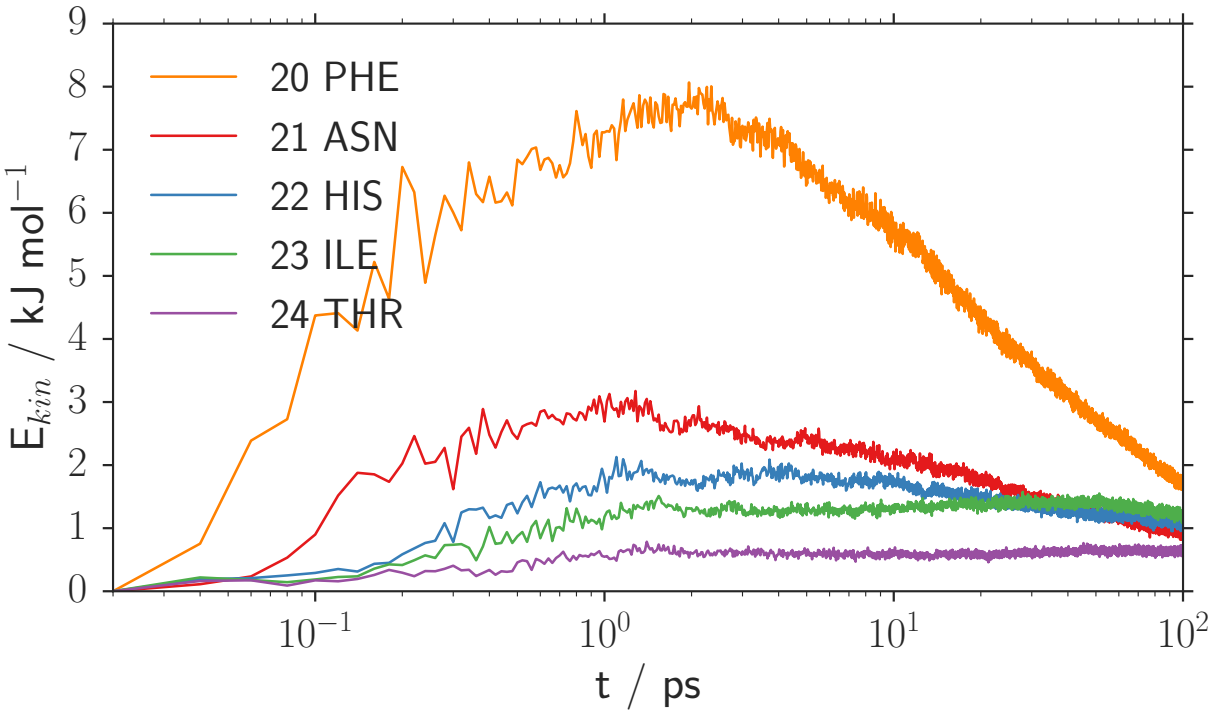

$\rightarrow \Delta E \approx 10 \frac{\text{kJ}}{\text{mol}}$ for direct neighbour

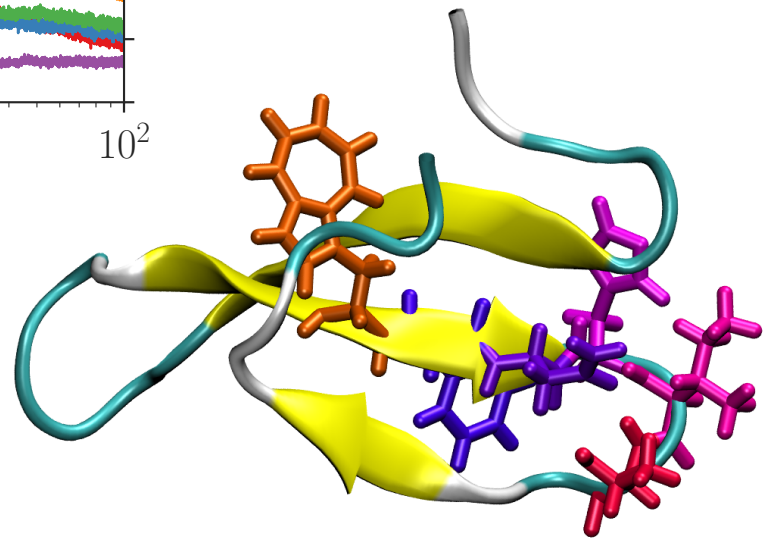


# Downstream neighbours

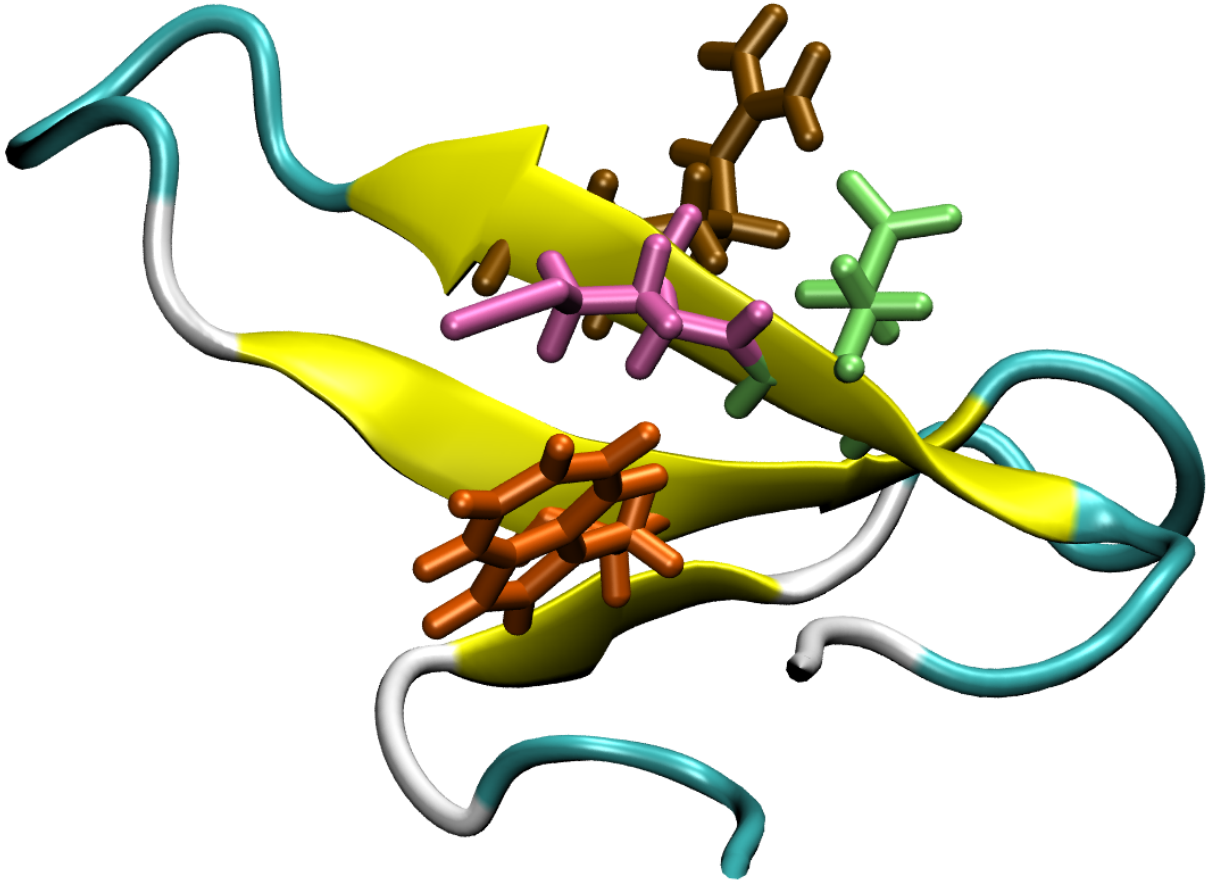


# Downstream neighbours



# Beta sheet neighbours



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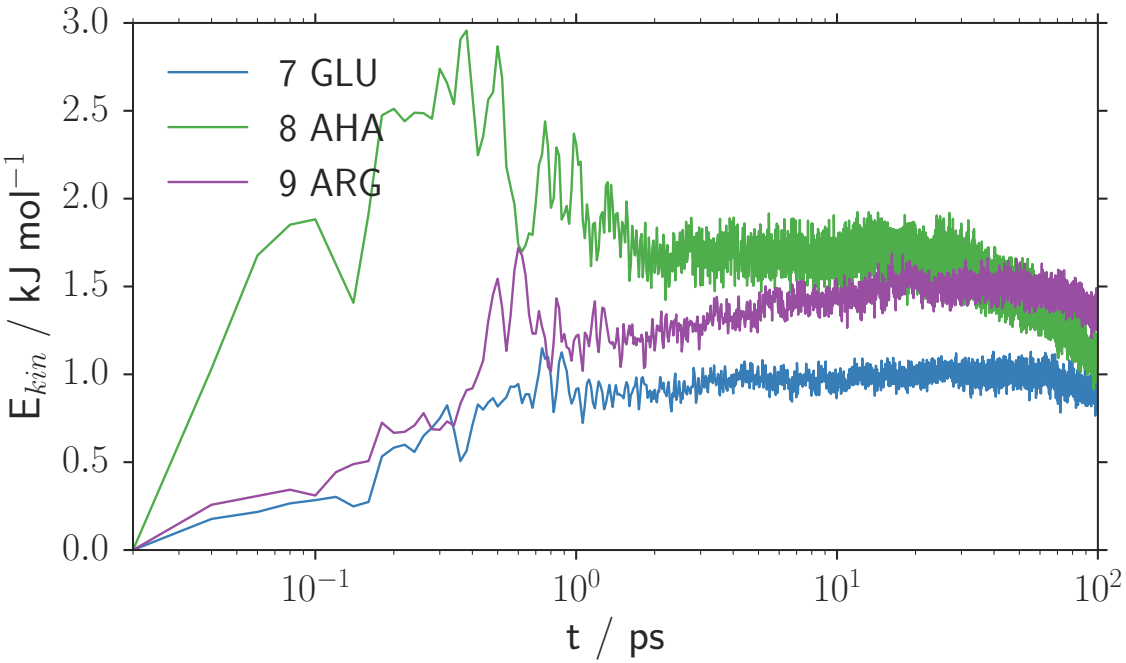
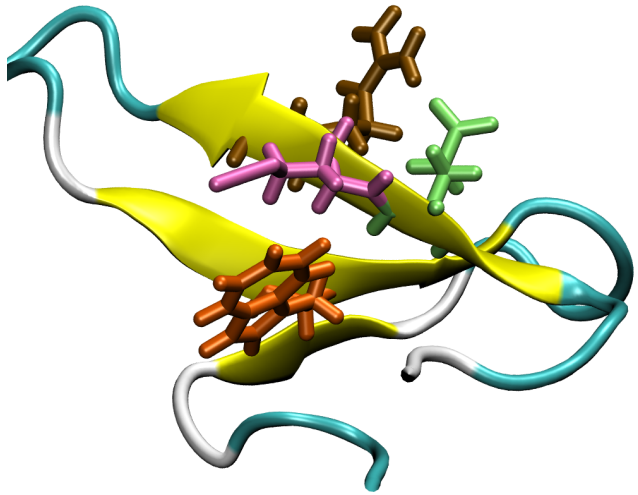
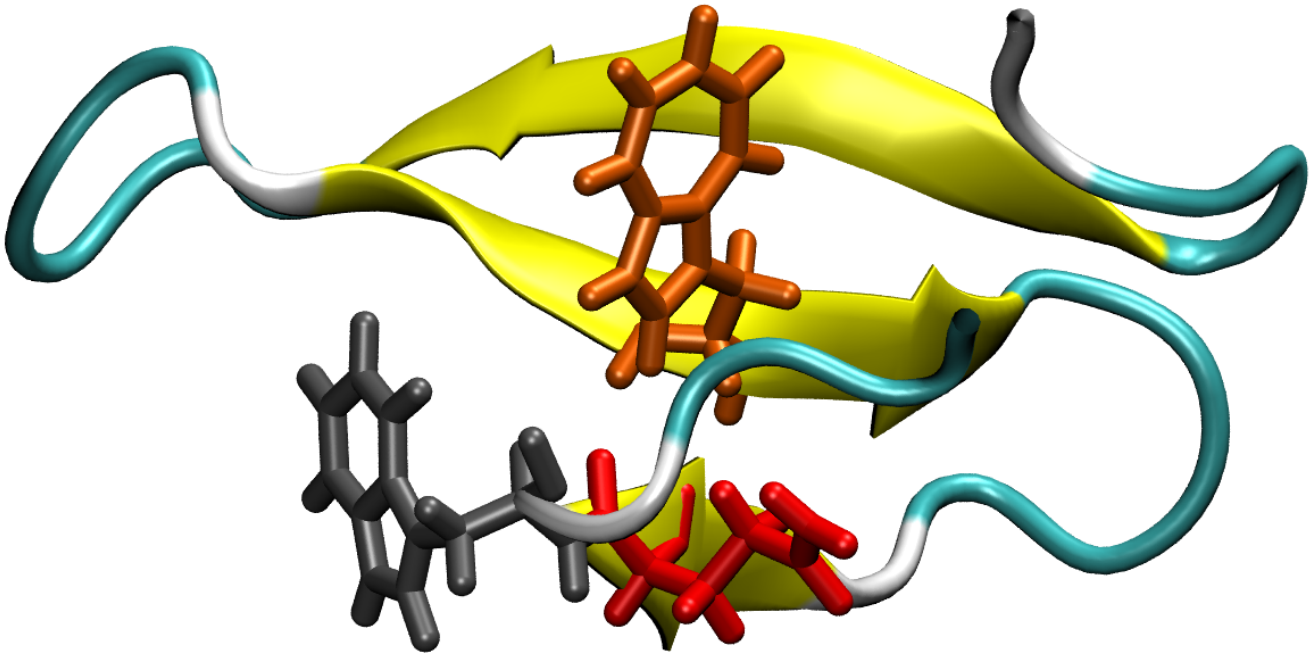


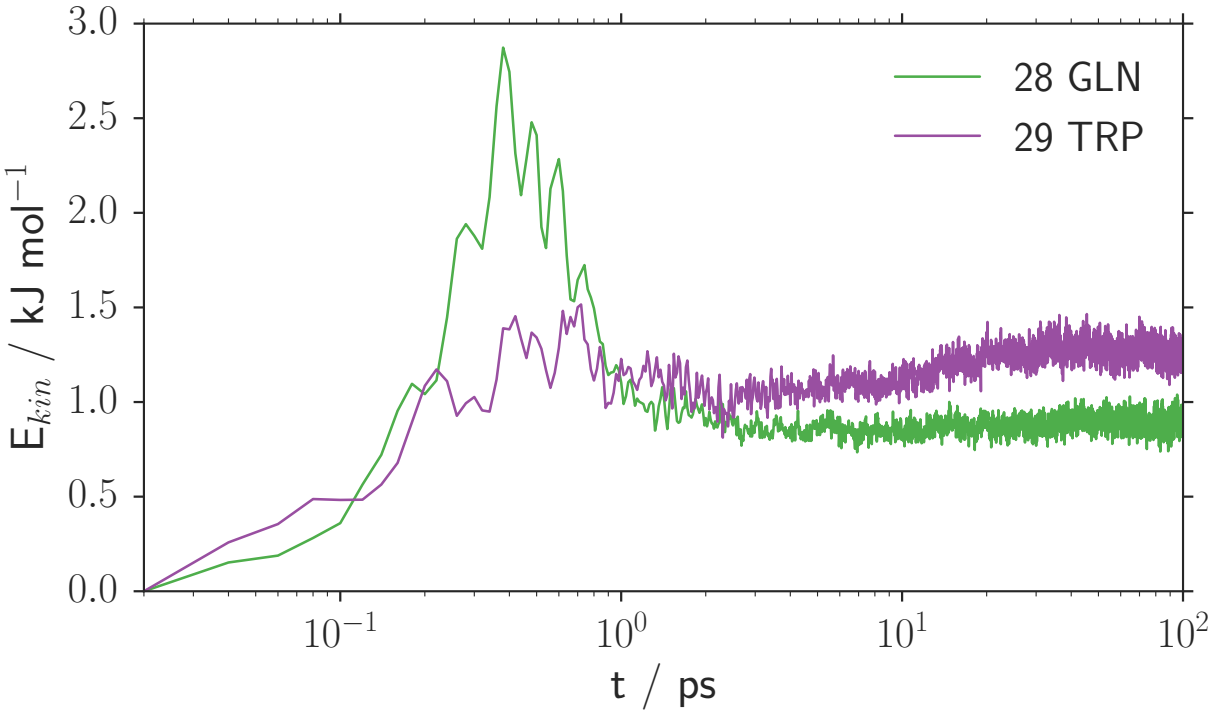



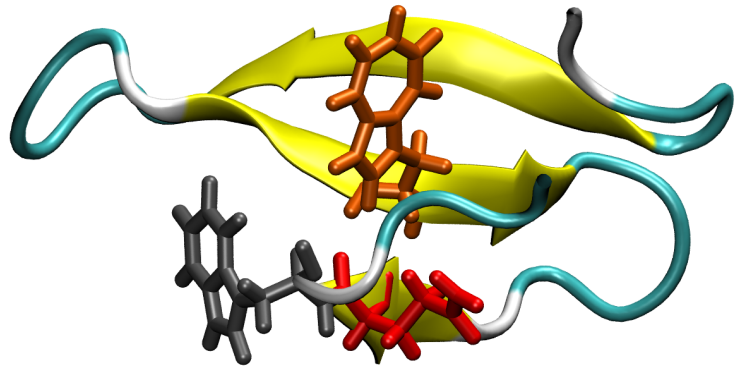
$\rightarrow$ role of sidechain contacts

# Beta sheet neighbours



# Beta sheet neighbours



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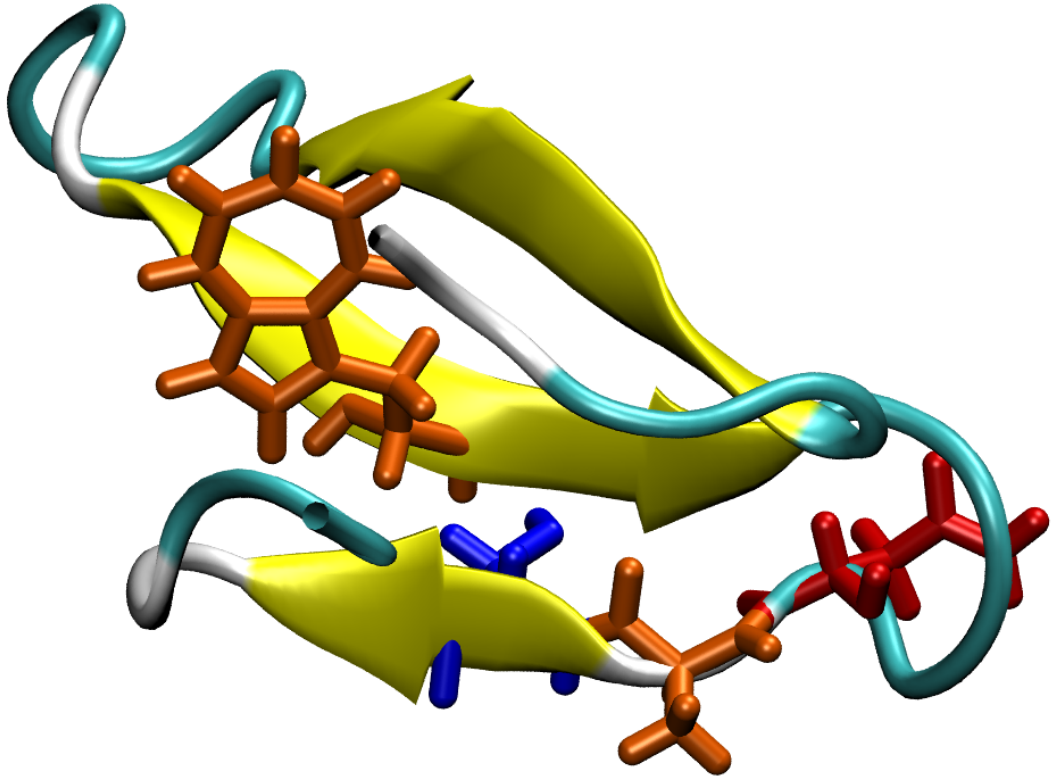
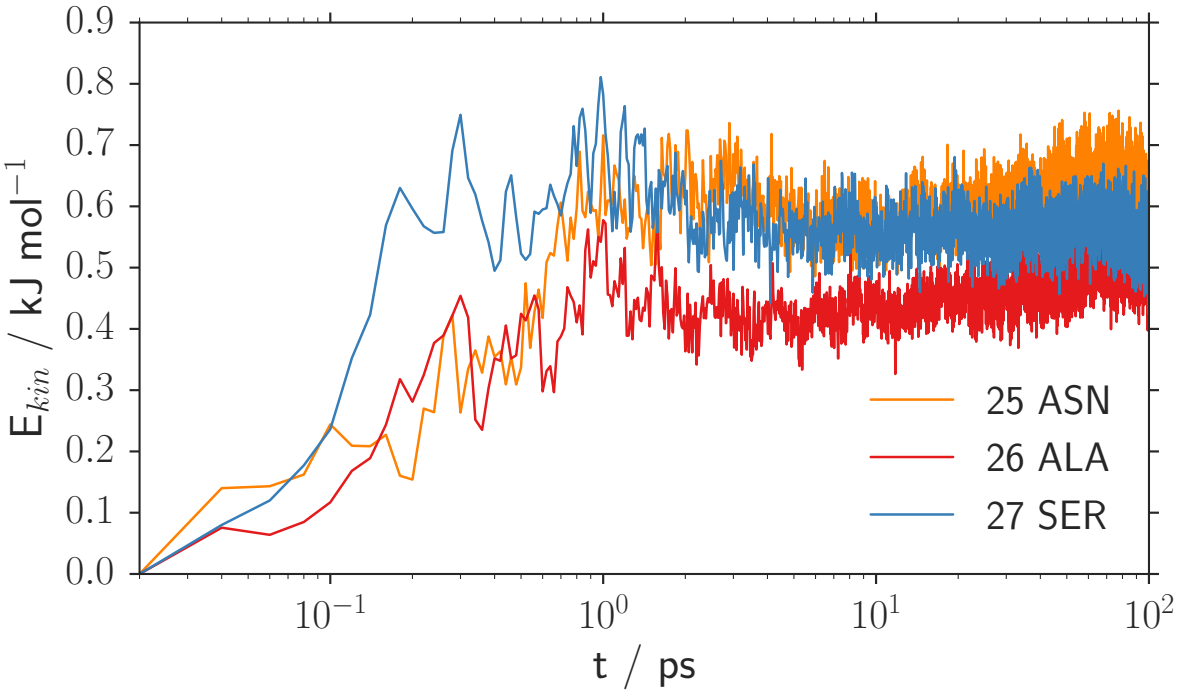
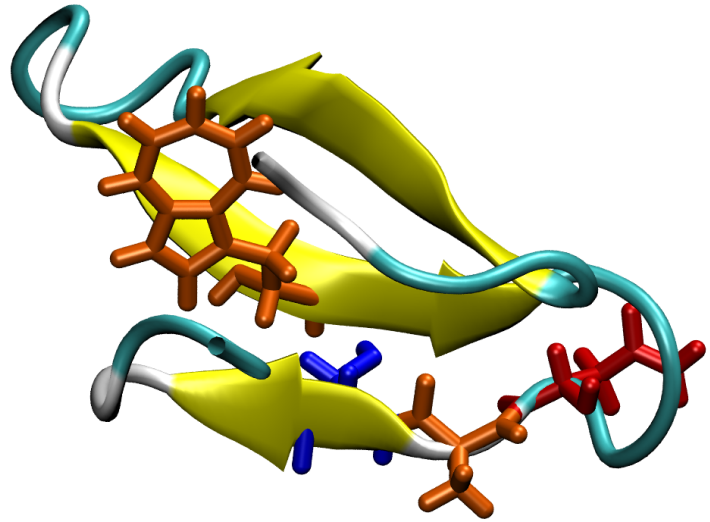


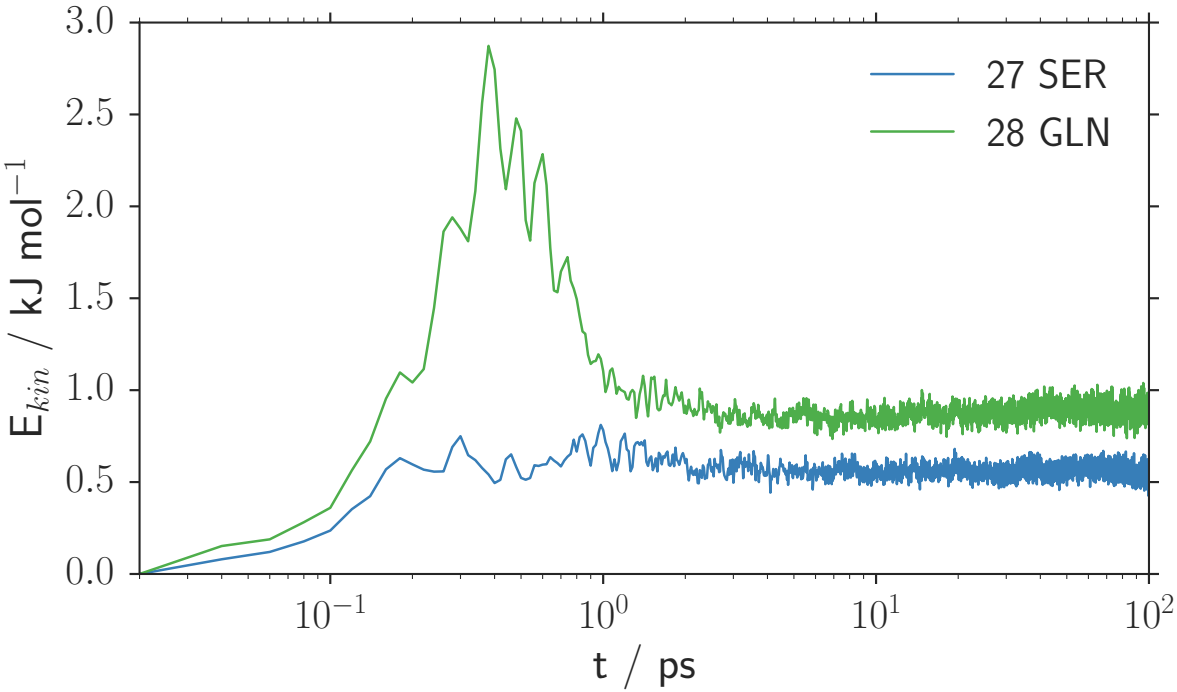
# Beta sheet neighbours



$\rightarrow \Delta E$ one order of magnitude smaller than for direct neighbours

# Beta sheet neighbours

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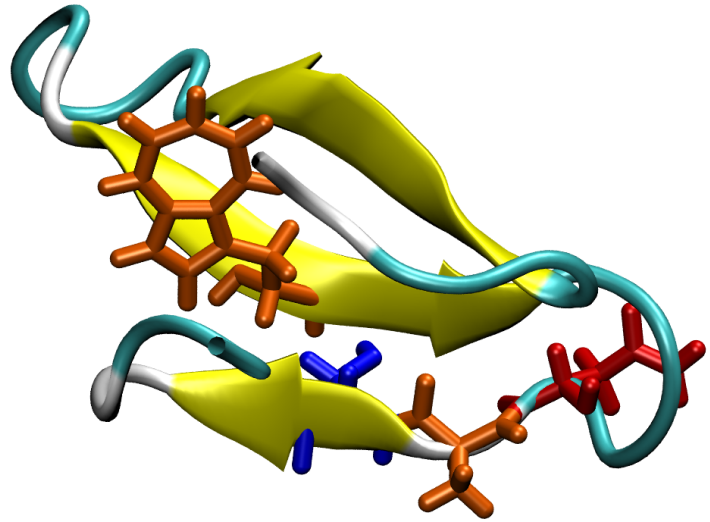

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# Rate model for VET

How can the vibrational energy transport be expressed in a simple model?

# Ansatz

$\rightarrow$ transition rate model for residues

## Master equation

Change in energy of residue $i$

$$\frac{dE_i}{dt} = \sum_j \left(k_{ji}E_j - k_{ij}E_i\right) - k_{i,S}E_i + k_{S,i}E_S,$$

with

| | |
|---|---|
| $k_{ij}$ | transition rate from residue $i$ to residue $j$ |
| $k_{i,S}$ | cooling rate from protein to solvent |
| $k_{S,i}$ | back rate from solvent to protein |

# Scaling rules

→ diffusion model and detailed balance condition for transition rates

## Backbone rates

$$k_{ij}^{B} = \frac{D_B}{\langle \Delta x_{ij} \rangle^2} \sqrt{\frac{f_j}{f_i}}$$

## Polar contact rates

$$k_{ij}^{C} = \frac{D_C}{\langle \Delta x_{ij}^2 \rangle} \sqrt{\frac{f_j}{f_i}}$$

With

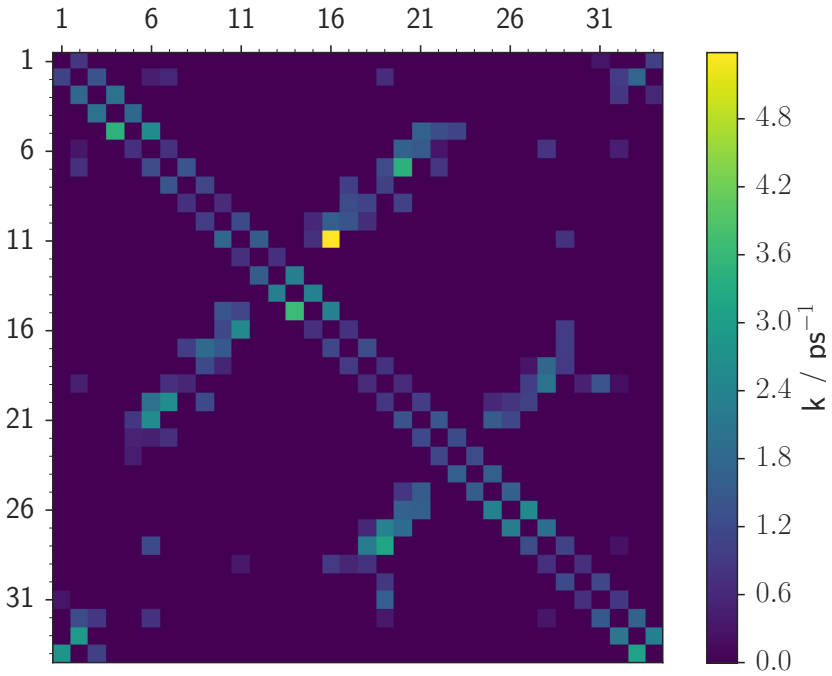
| | |
|---|---|
| $f$ | degrees of freedom |
| $\Delta x$ | distance between closest atoms |

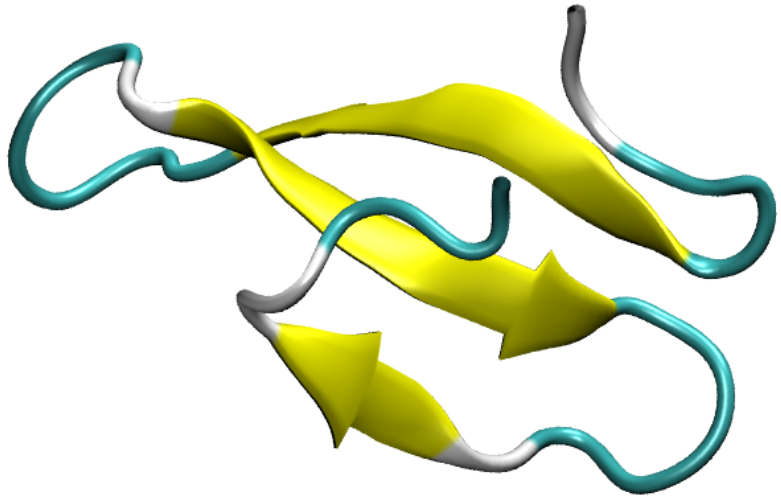
# Rate model for VET

Can we apply the model, including the diffusion constants, globally if T is constant?

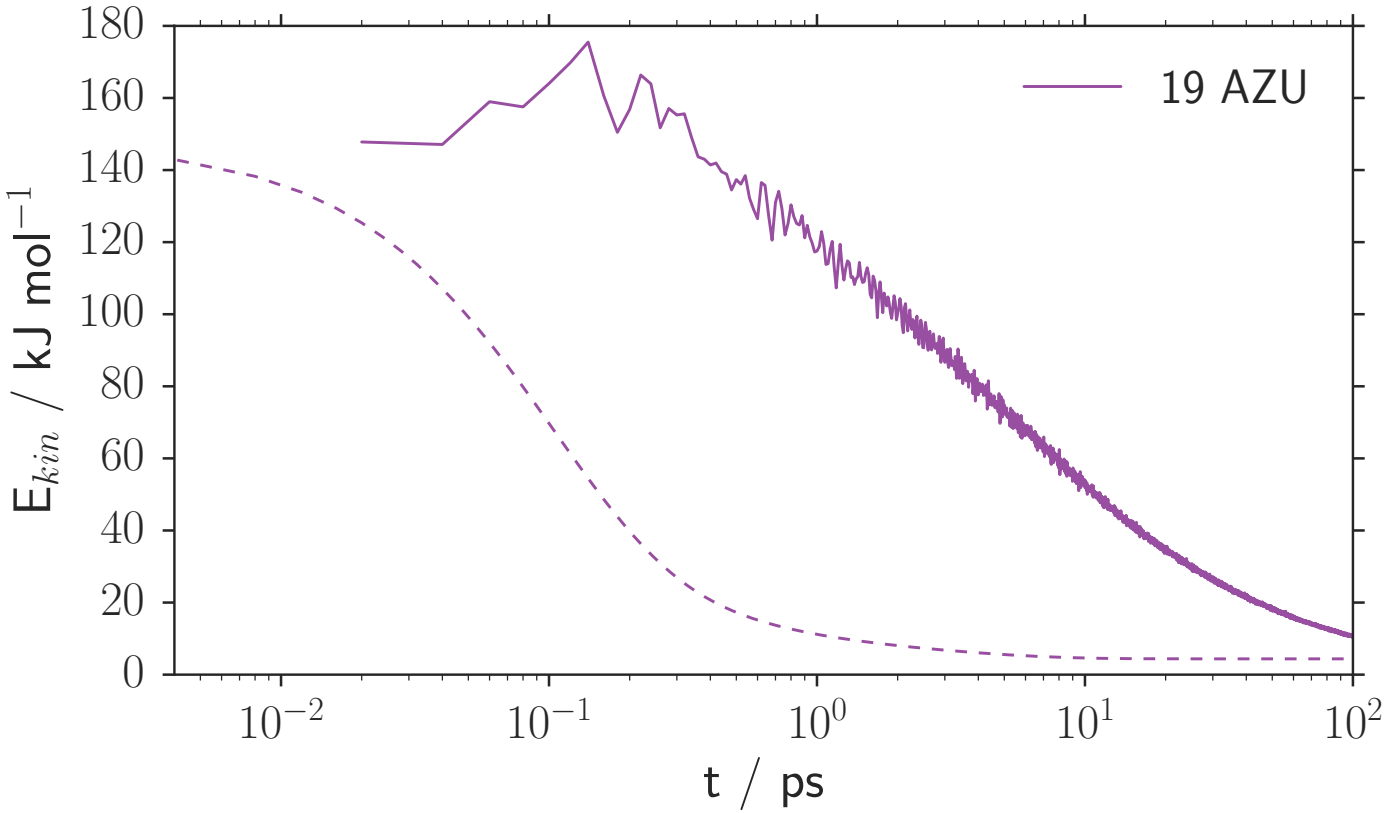
# Transition rates

- Polar + backbone rates



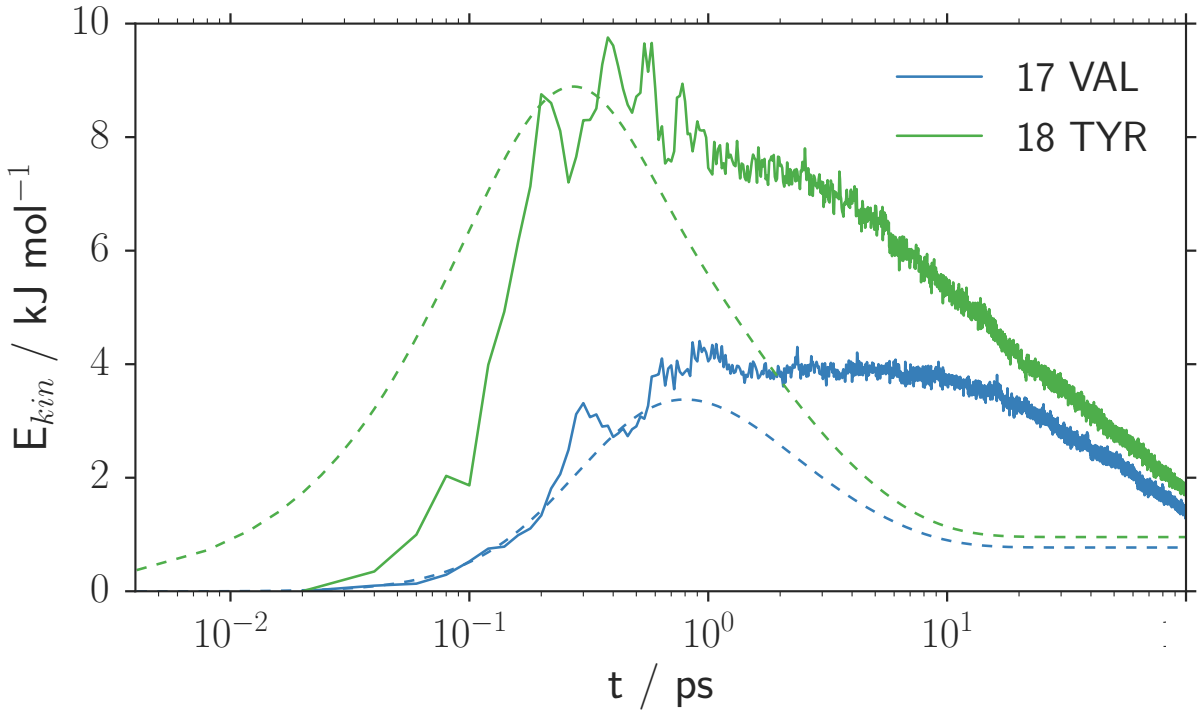



# MEQ Results - Heater

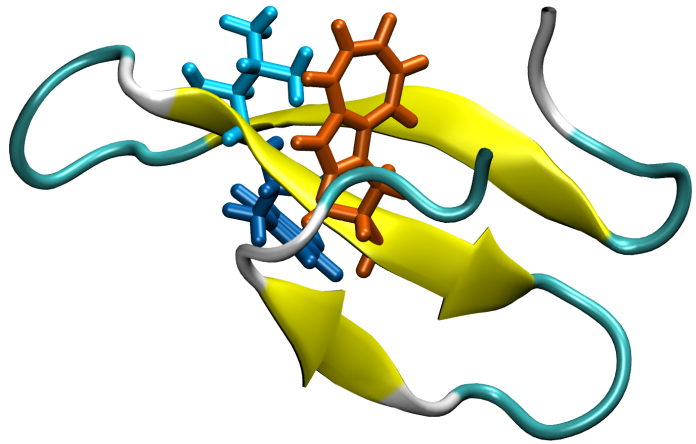



$\rightarrow$ excited limbo state 19*?

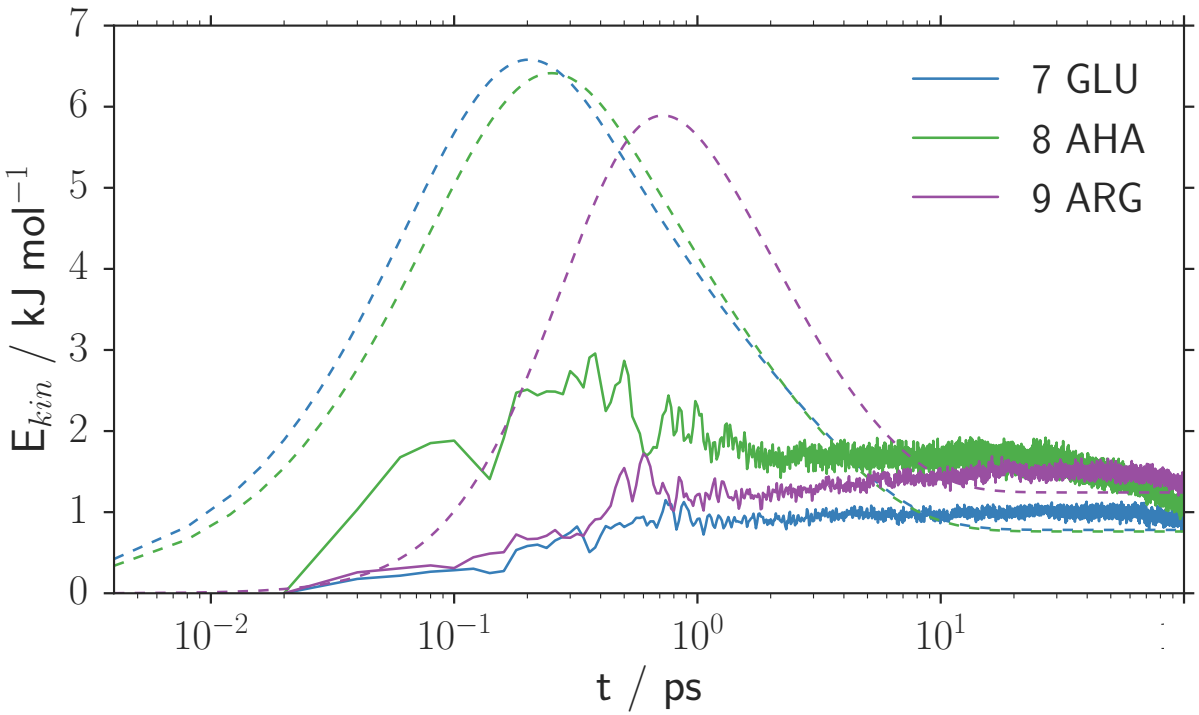
# MEQ Results - Neighbours



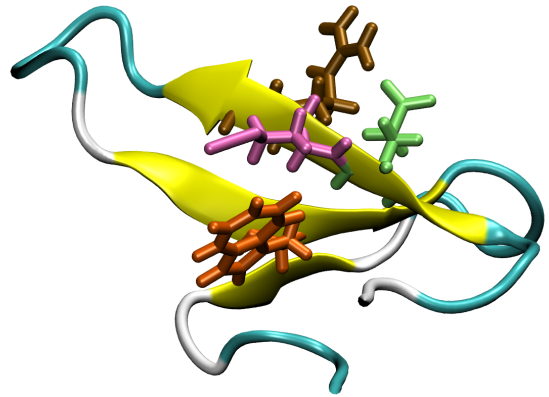

→ shoulder to the right?



# MEQ Results - Polar contacts




→ overestimation of $D_C$?



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# Conclusion

- MD results
  - direct neighbours 18TYR and 20PHE receive 7-10 $\frac{\text{kJ}}{\text{mol}}$
  - beta sheet “neighbours” 8AHA and 28GLN receive $\approx 3 \frac{\text{kJ}}{\text{mol}}$
  - bottlenecks in backbone transport

- Rate model
  - decay process of AZU slower
  - magnitude of energy transport good for direct neighbours
  - polar contact rates too high

# Outlook

- Comparison to experiment
  - behaviour of AHA modes
  - propagation along sidechains
- Rate model
  - fit a model with excited limbo state 19*
  - fit diffusion constants $D_C$ and $D_B$ and compare to other systems

# References I


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A donor-acceptor pair for the real time study of vibrational energy transfer in proteins.
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S. Buchenberg, D. Leitner and G. Stock
Scaling Rules for Vibrational Energy Transport in Globular Protein.
**J.Phys.Chem.Lett.**, 7:25–30, 2016.

D. Leitner, S. Buchenberg, P. Brettel and G. Stock
Vibrational energy flow in the villin headpiece subdomain: Master equation simulations.
**J.Chem.Phys.** 142, 075101, 2015.

# Thanks for the attention!