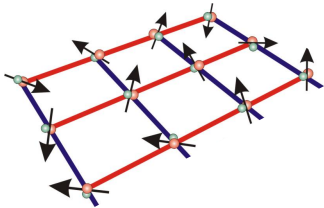


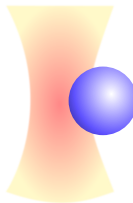
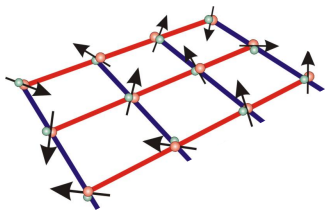
Shortcuts to adiabaticity



adiabatic quantum computing:
maintaining ground state while
driving a quantum system

Demirplak, Rice, JPCA (2003)
Berry, J. Phys. A (2009)

Shortcuts to adiabaticity



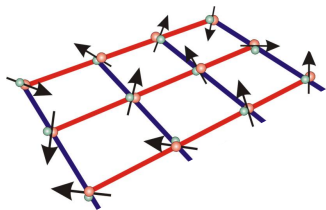
adiabatic quantum computing:
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**Brownian motion of
bead in optical trap:**
maintaining instantaneous
equilibrium as trap changes

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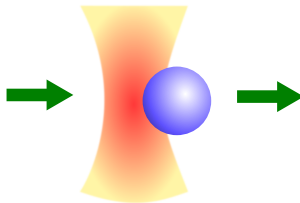
Martinez *et al* Nature Physics (2016)
Patra, Jarzynski, New. J. Phys. (2017)

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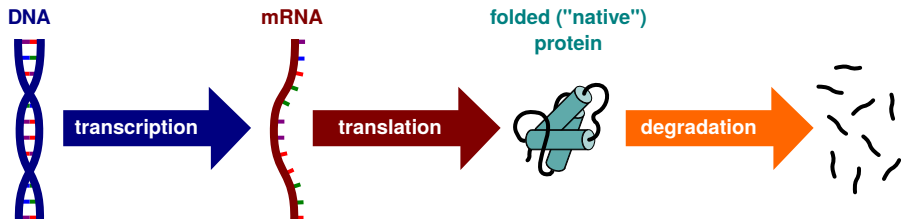
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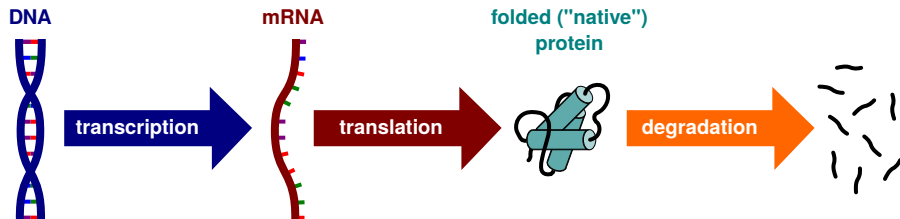


**Possible biological
applications:**
population genetics
molecular chaperones
force spectroscopy

Traditional view of protein production



Traditional view of protein production



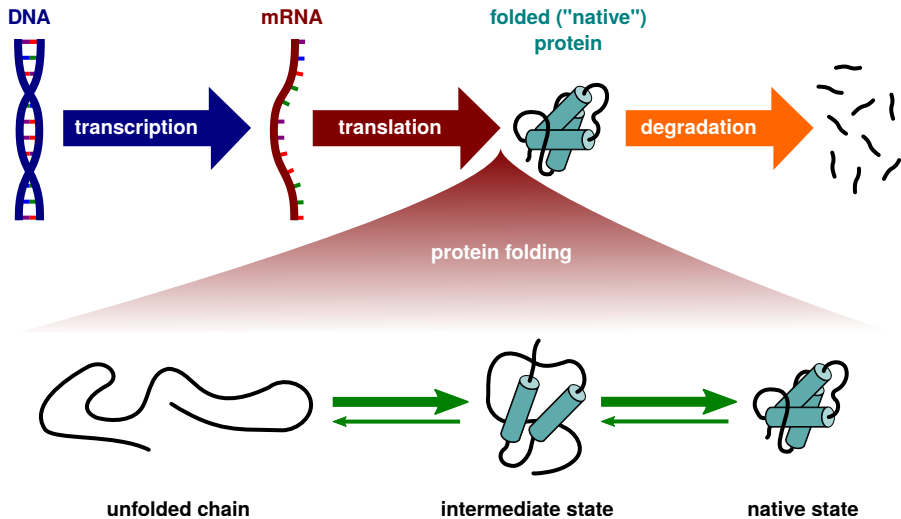
All these processes involve nonequilibrium reaction networks driven by ATP hydrolysis.

The resulting costs of expressing even a single extra protein can be evolutionarily significant for single-celled organisms.

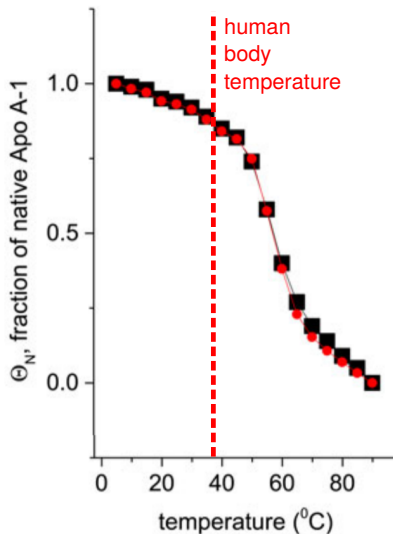
Ilker & Hinczewski, *Phys. Rev. Lett.* (2019)

Lynch & Marinov, *Proc. Natl. Acad. Sci.* (2015)

Traditional view of protein production

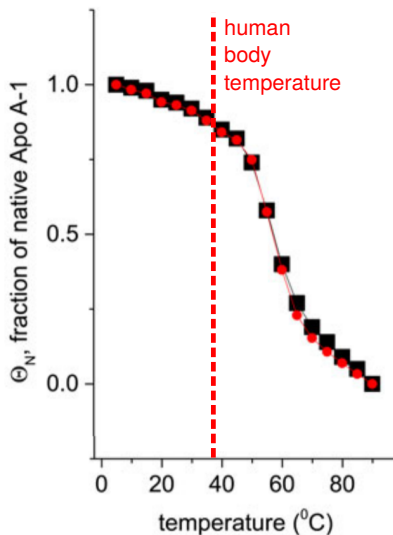


Proteins function at the cliff edge of unfolding



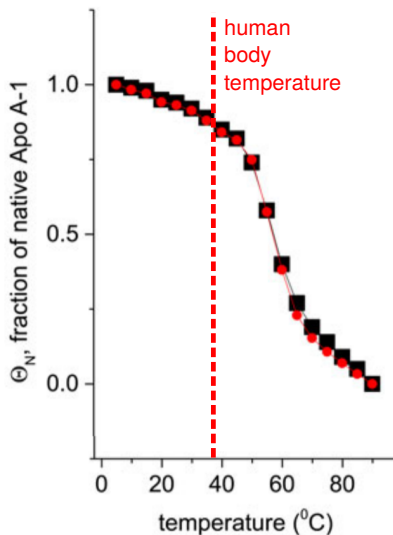
Seelig & Schönfeld, Q. Rev. Biophys. (2016)

Proteins function at the cliff edge of unfolding



Being on the verge of melting gives proteins the **dynamical flexibility** essential for their diverse roles as enzymes.

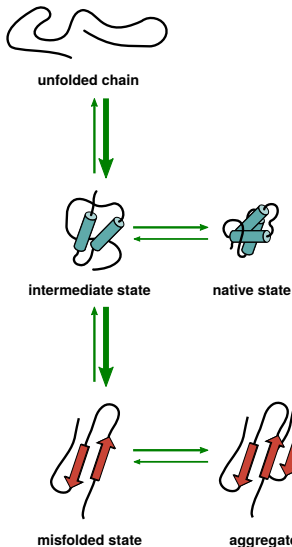
Proteins function at the cliff edge of unfolding



Being on the verge of melting gives proteins the **dynamical flexibility** essential for their diverse roles as enzymes.

But it also makes them highly vulnerable to changes in temperature (even of a few degrees): **heat shock**.

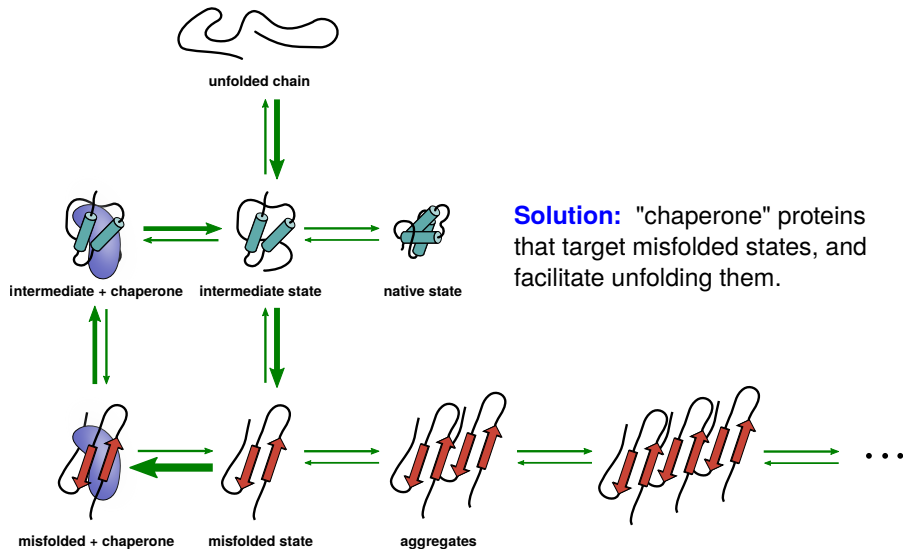
Constant threats: misfolding and aggregation



Even at normal temperatures, many proteins tend to **misfold** into states that lead to potentially lethal **aggregates**.

This problem is exacerbated as temperature increases.

Constant threats: misfolding and aggregation



Constant threats: misfolding and aggregation



unfolded chain



intermediate + chaperone



intermediate state



native state

These chaperones are typically enzymes that hydrolyze ATP.

This leads to a **nonequilibrium stationary distribution** for the state probabilities of the protein.

Chakrabarti *et al.*, PNAS (2017)

Goloubinoff *et al.*, Nat. Chem. Biol. (2018)



misfolded + chaperone



misfolded state

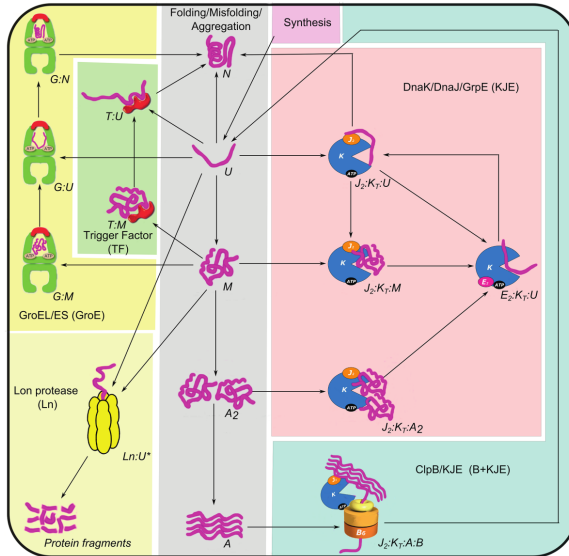


aggregates



...

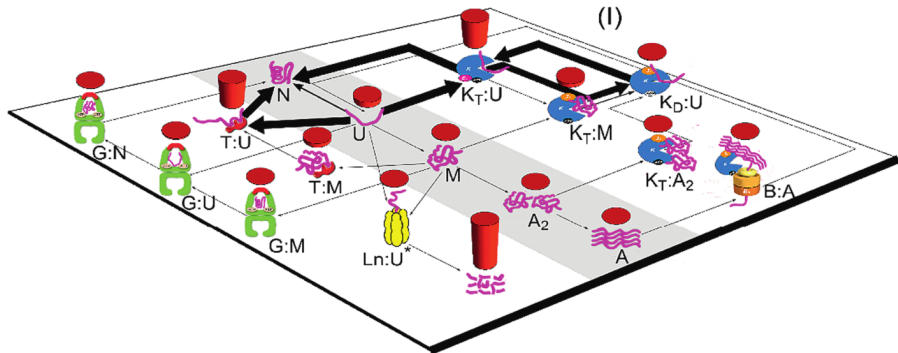
The protein “hospital”: possible chaperone pathways



E. coli chaperone network: Santra *et al.*, PNAS (2017)

The protein “hospital”: possible chaperone pathways

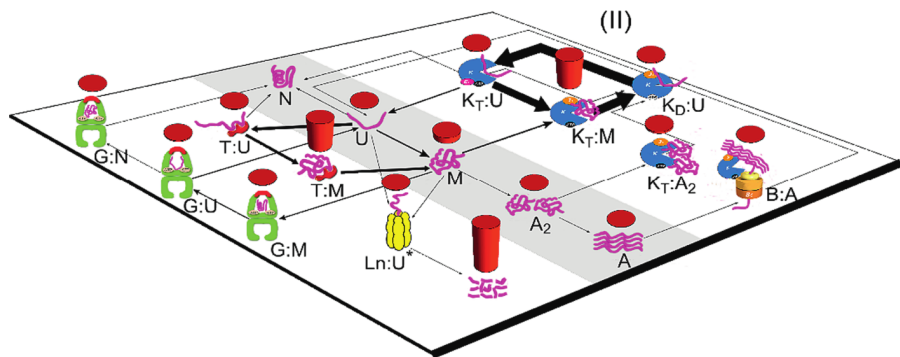
Different classes of proteins interact primarily with different chaperone sub-systems:



Santra *et al.*, PNAS (2017)

The protein “hospital”: possible chaperone pathways

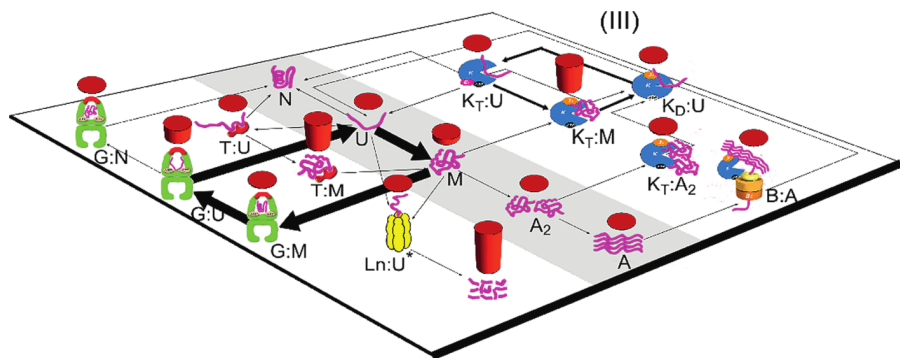
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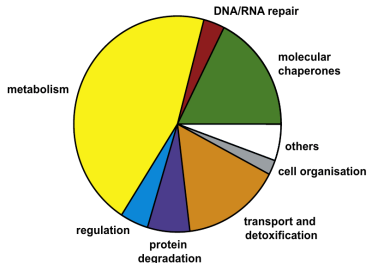


Santra *et al.*, PNAS (2017)

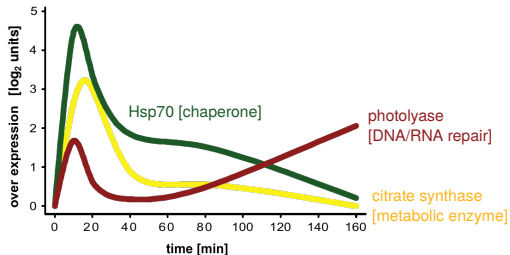
Under optimal growth conditions, chaperones are nearly fully occupied by “patient” proteins: spare capacity is too energetically costly.

Example: heat shock response in yeast

Functional classes of upregulated genes in yeast after a heat shock from 25°C to 35°C over 10 min:



[Total: 91 genes upregulated by more than 2.8x]



[Richter *et al.*, Molec. Cell (2010)]