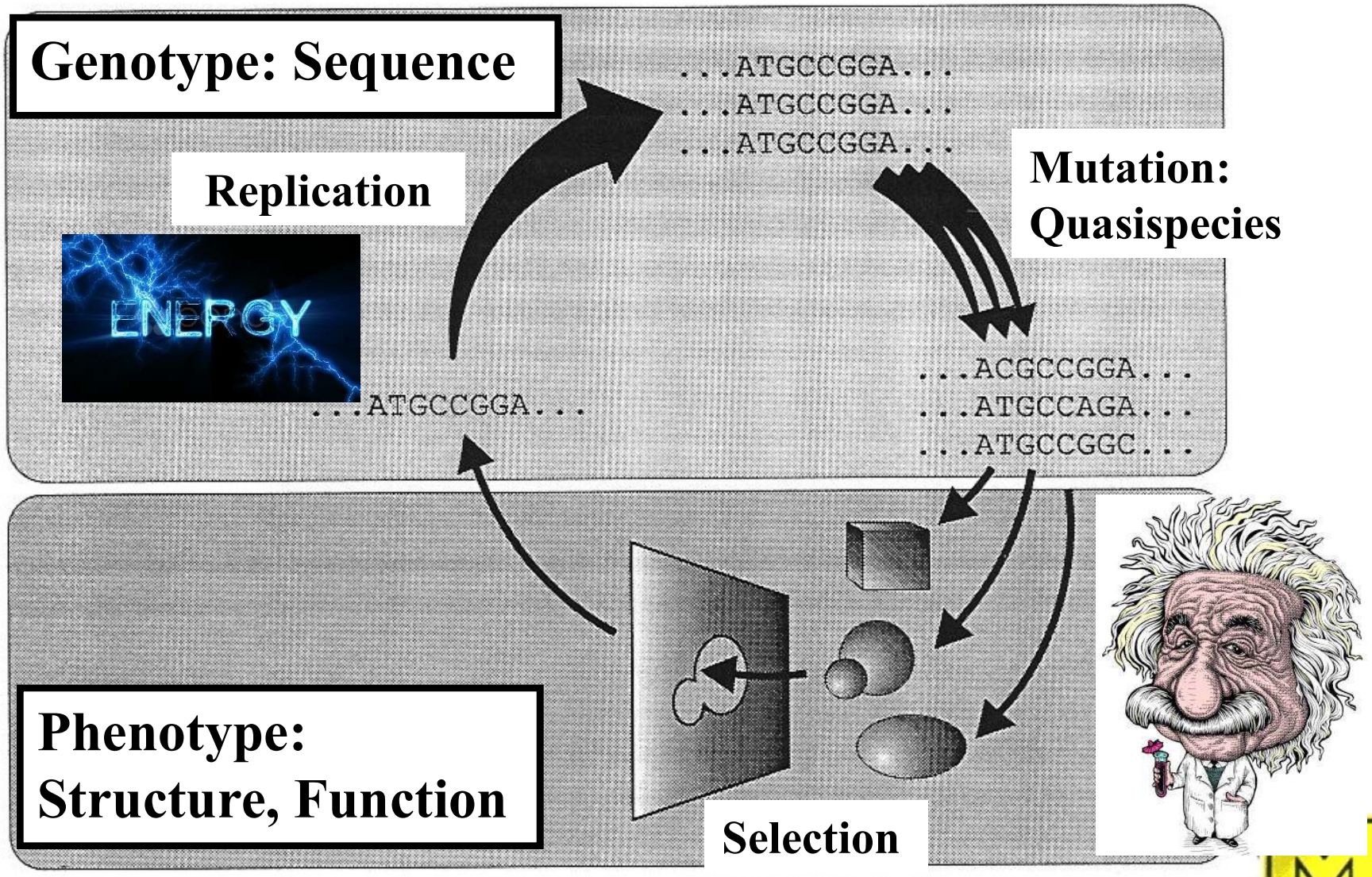
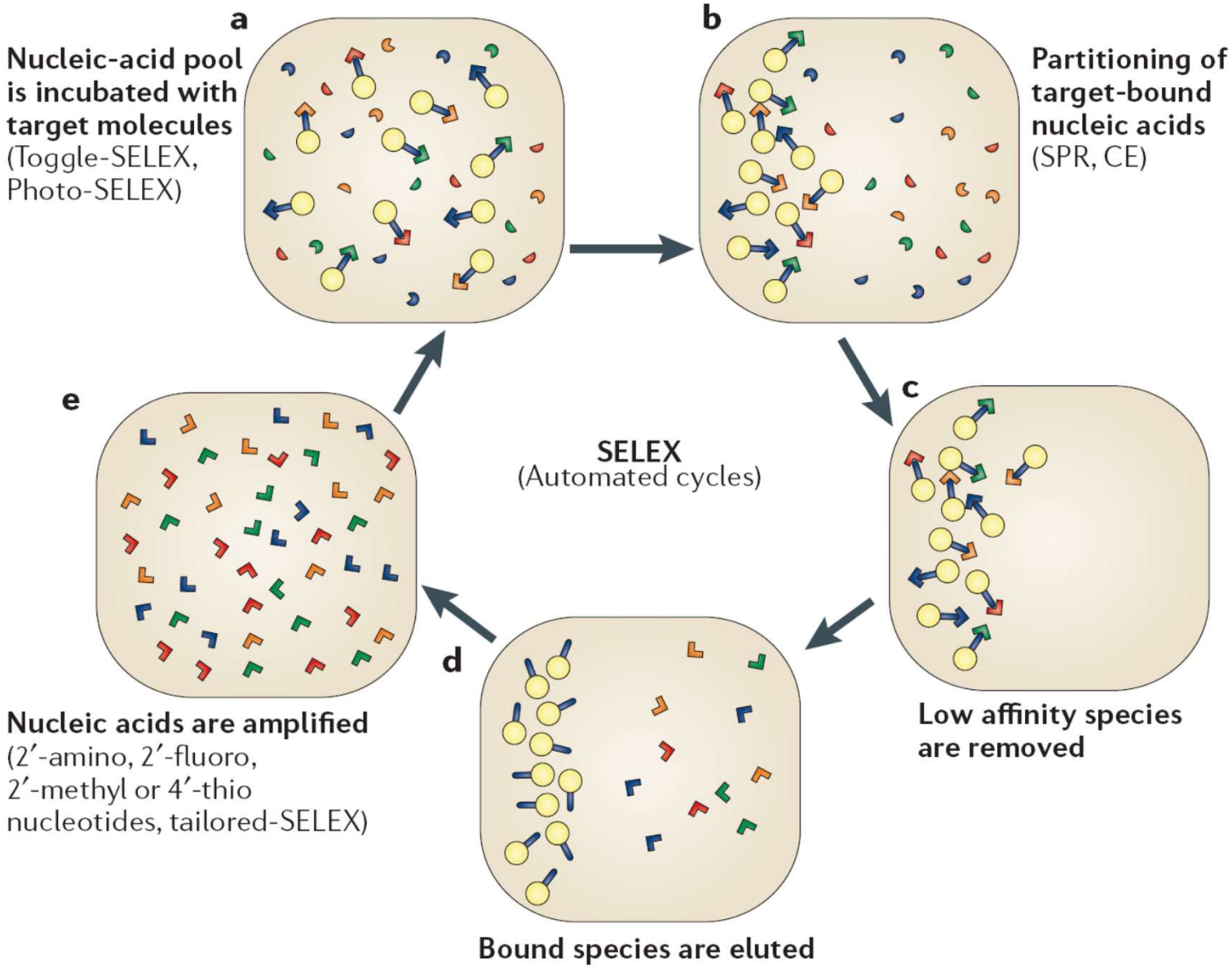
Driving force of evolution: Darwinian chemistry – Replication, Mutation, Selection

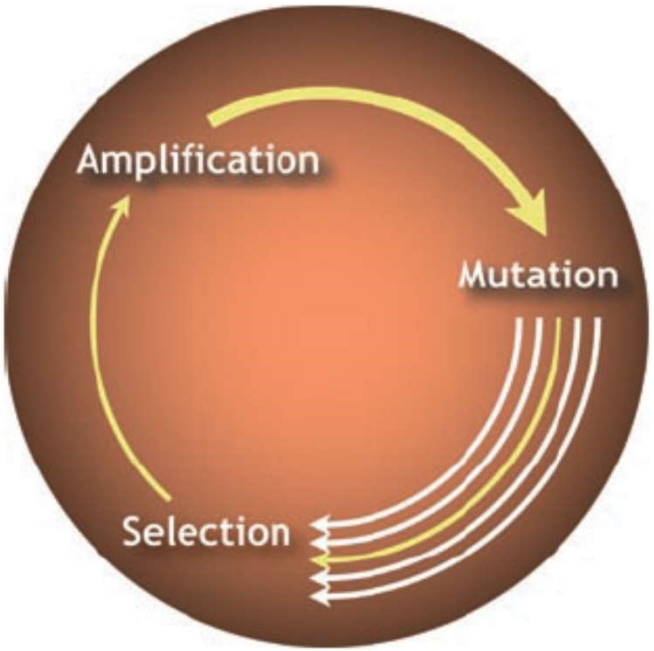


How is this done in practice?

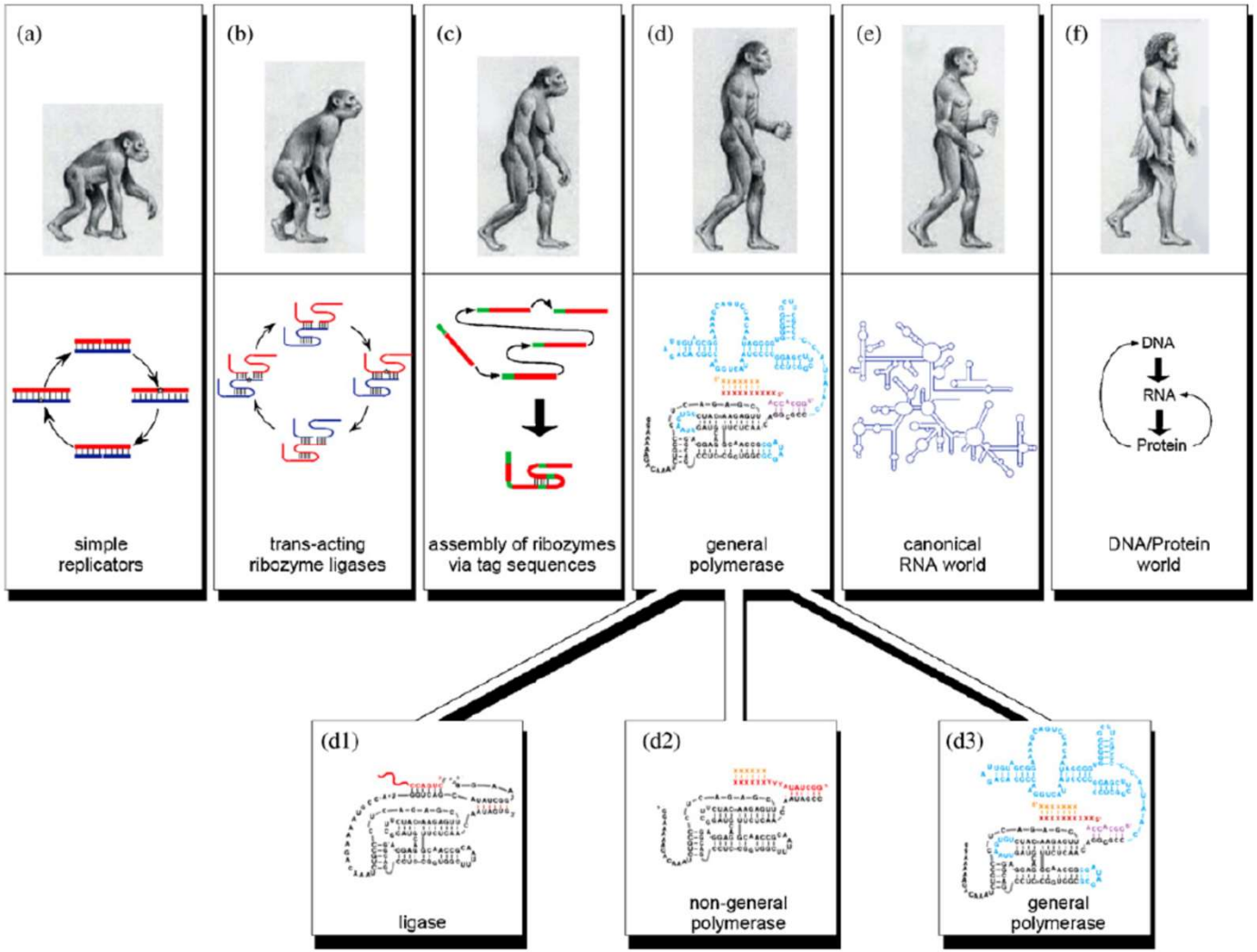


Bunka, D.H.J. and Stockley, P.G. *Nat. Rev. Microbiol.* 4 (2006) 588-596

In vitro Evolution of ribozymes yields more diversity and a link to the origin of life

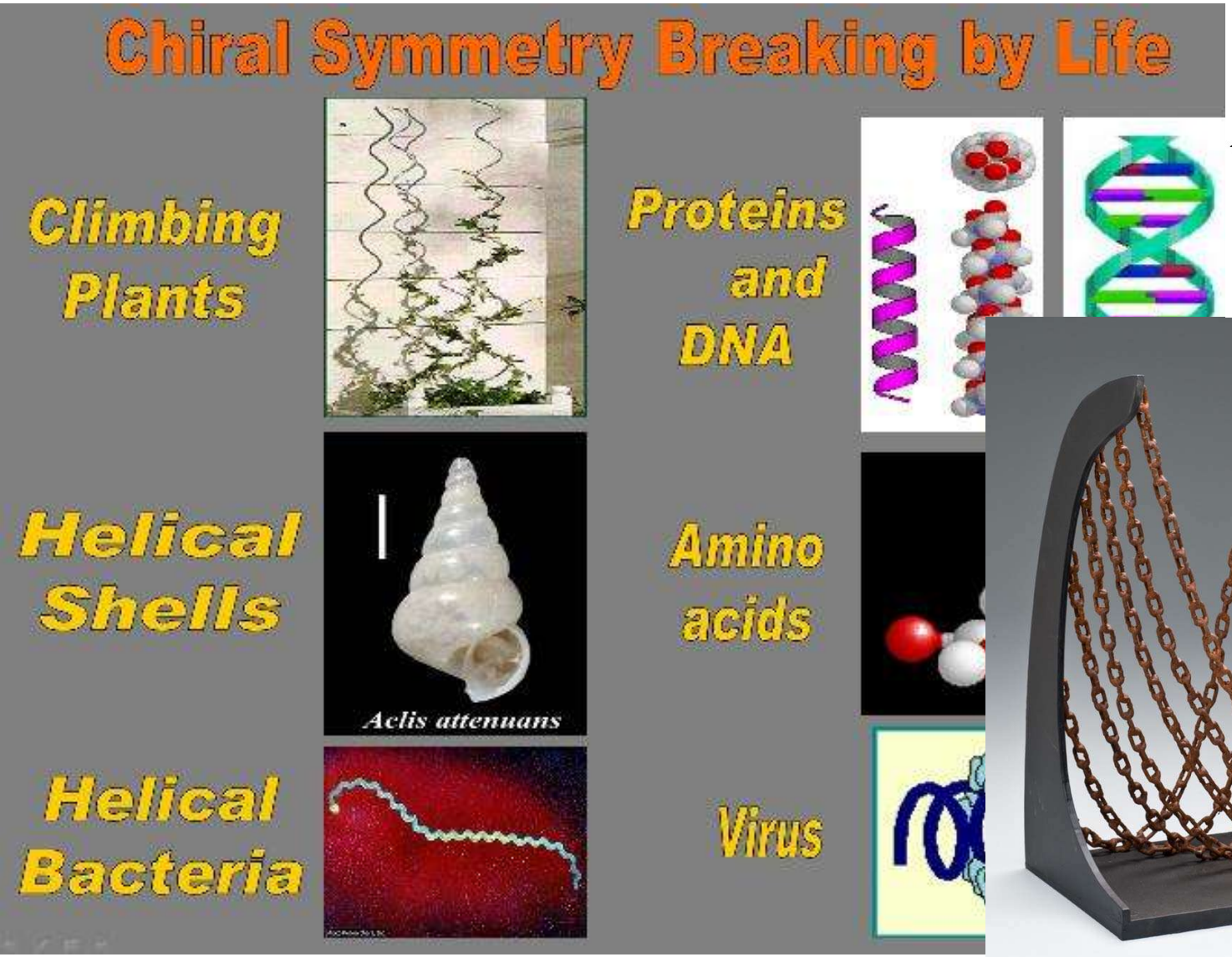


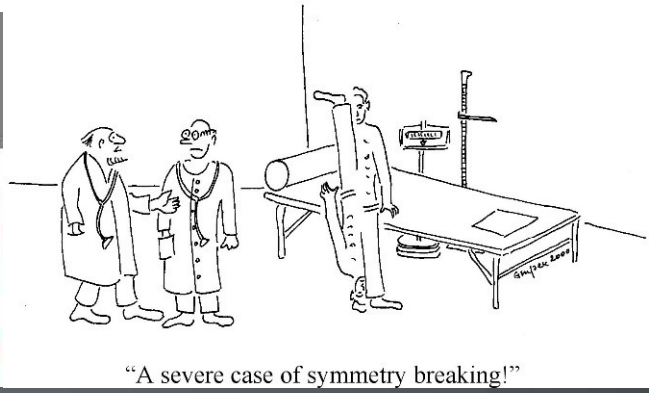
Joyce, G.F. *Angew. Chem. Int. Ed. Engl.* 46 (2007) 6420-6436



Ellington A.D., Chen X., Robertson M., and Syrett A. *Int. J. Biochem. Cell Biol.* 41 (2009) 254-265

Symmetry breaking also had to happen (spontaneously) – e.g., to favor a specific chirality





"A severe case of symmetry breaking!"

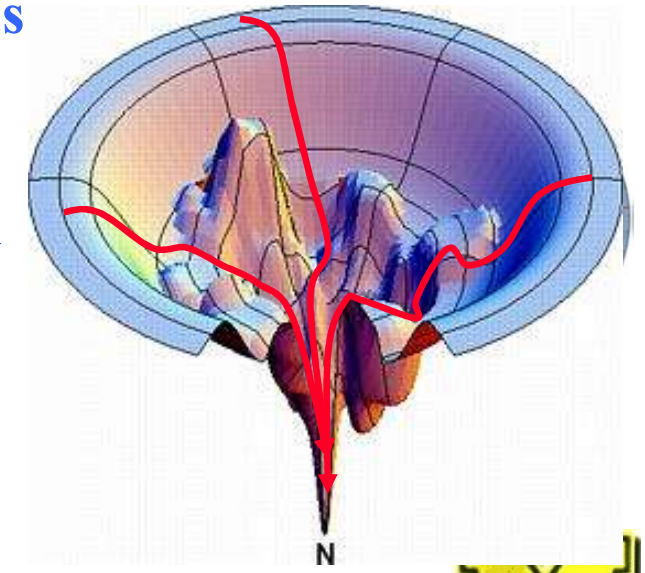
The first life form: Improbable or Inevitable?

Improbability Argument: Steering a mixture of all monomer building blocks of a bacterium, the odds that a single bacterium re-assembles by chance is one in $10^{100,000,000,000}$

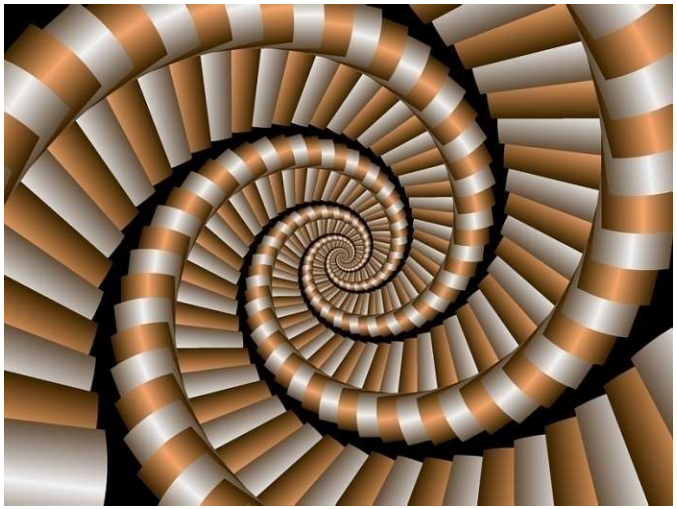
Reality Check: Is Nature working as a "Blind Watchmaker"?

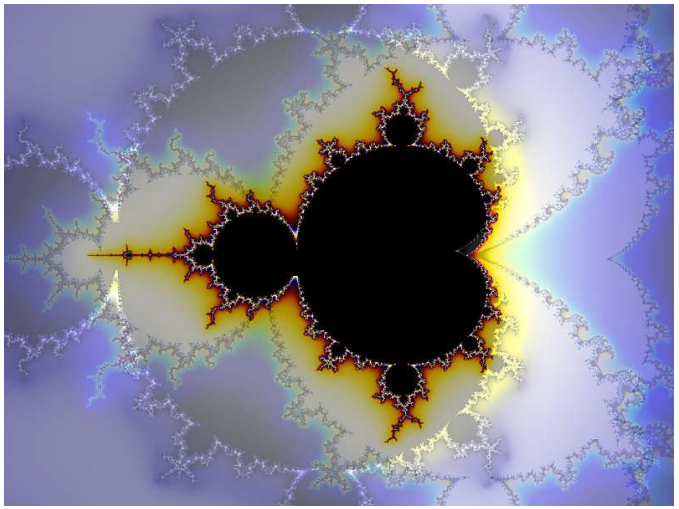
Of course not: Example protein folding

- **Levinthal's paradox:** A 100-amino acid protein has an estimated $N = 9^{98} \approx 3 \times 10^{93}$ possible conformations ⇒ It is improbable that even a single protein would fold into a functional form in our bodies, if only random search were at work
- But in reality there are many parallel pathways that go through intermediate states, making the success rate MUCH higher ⇒ protein folding is inevitable (deterministic) & so we live!

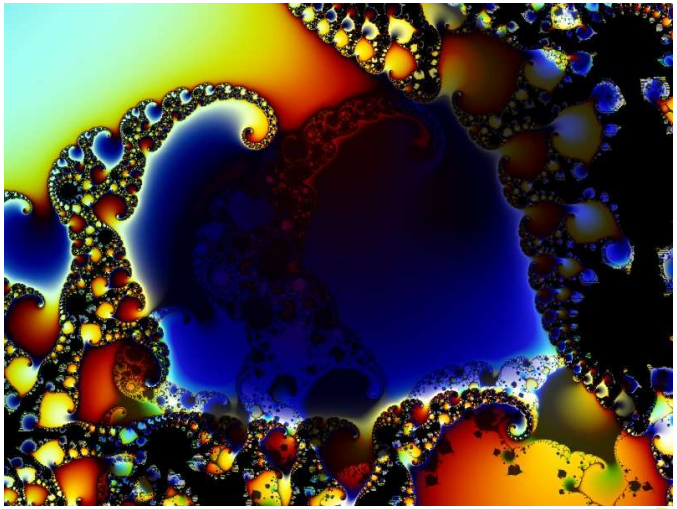


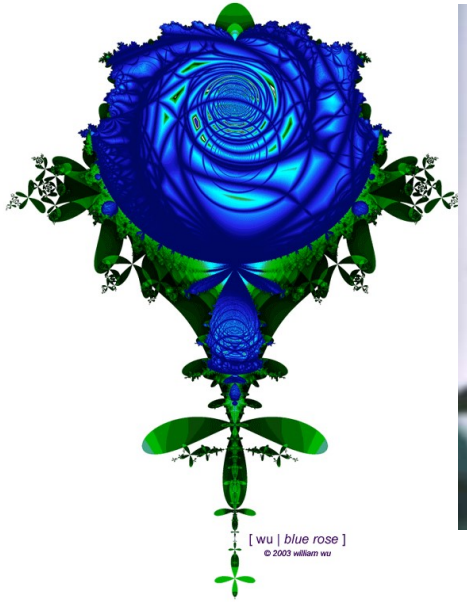
Towards ever higher complexity – why, and what are fractals?





$$z = z^2 + c$$

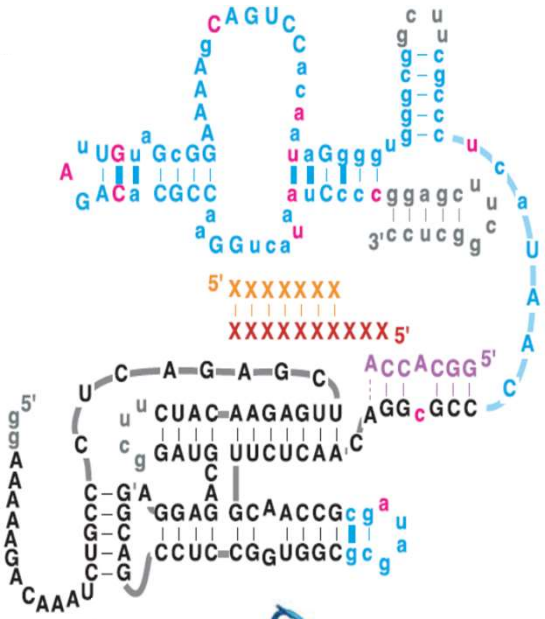


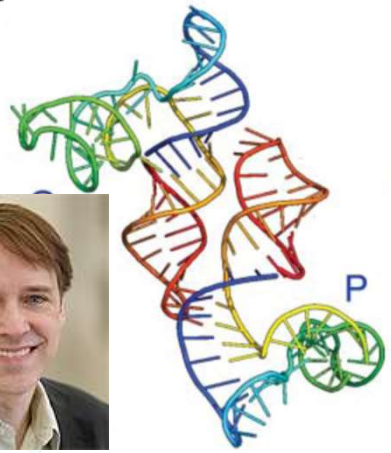


- Fractals are complex, self-similar geometric structures from simple mathematical rules
- feedback loops generate such fractal geometries in nature

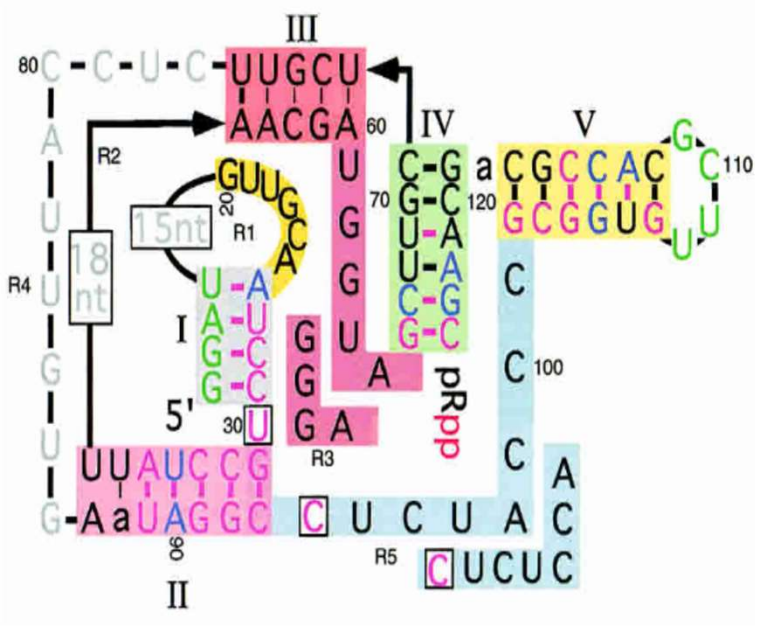
Rebuilding the RNA World, one function at a time

RNA Replicase: 2001, Bartel et al.

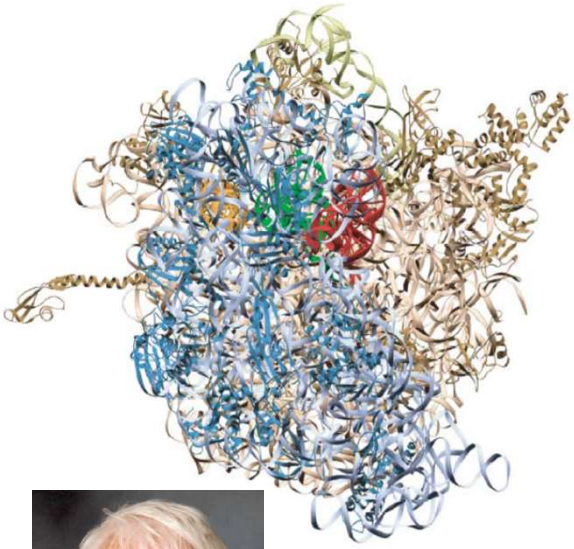




RNA Nucleotide Synthase: 1998, Unrau & Bartel

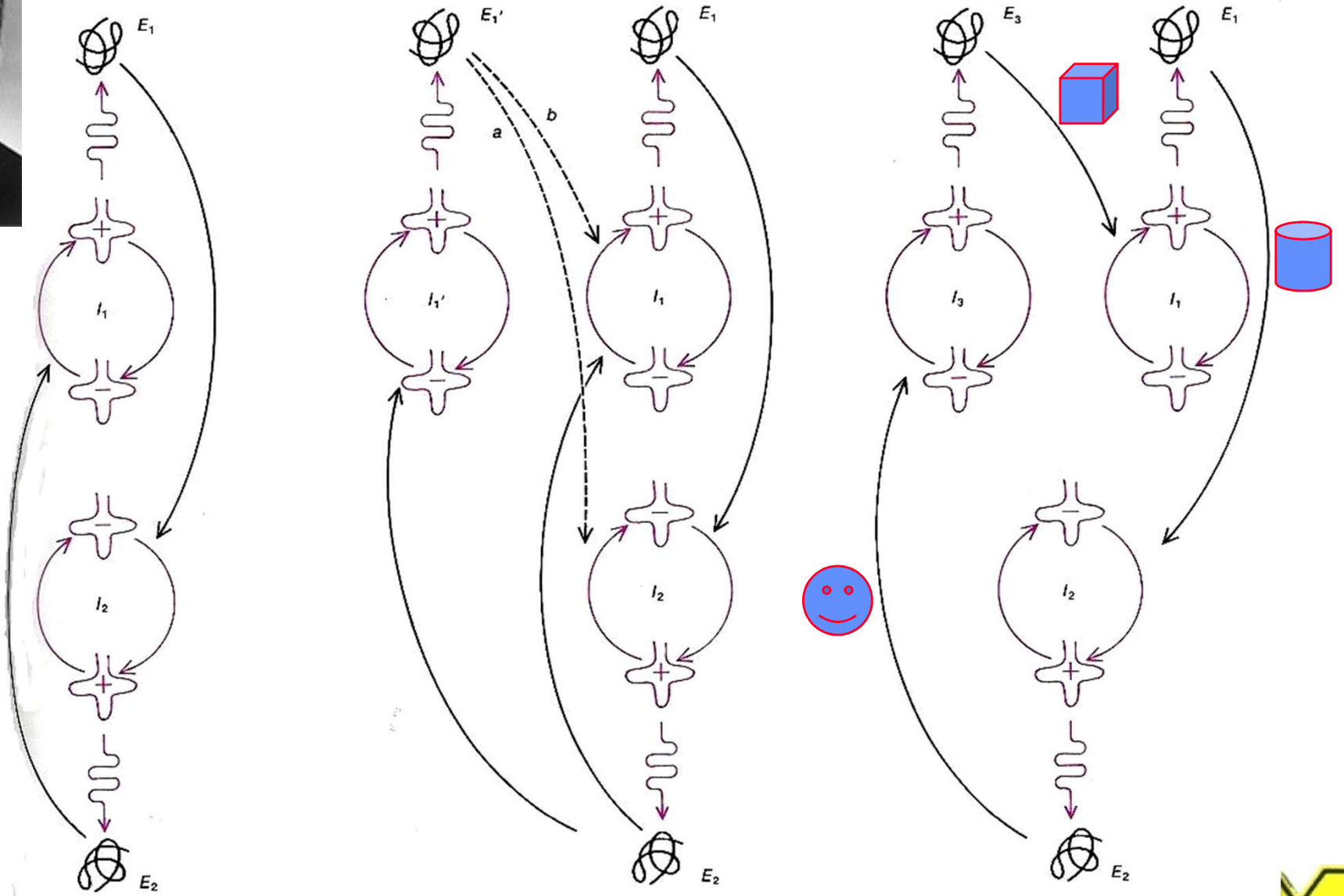


Peptide bond formation by the ribosome is catalyzed by the RNA component: 2000, Moore & Steitz



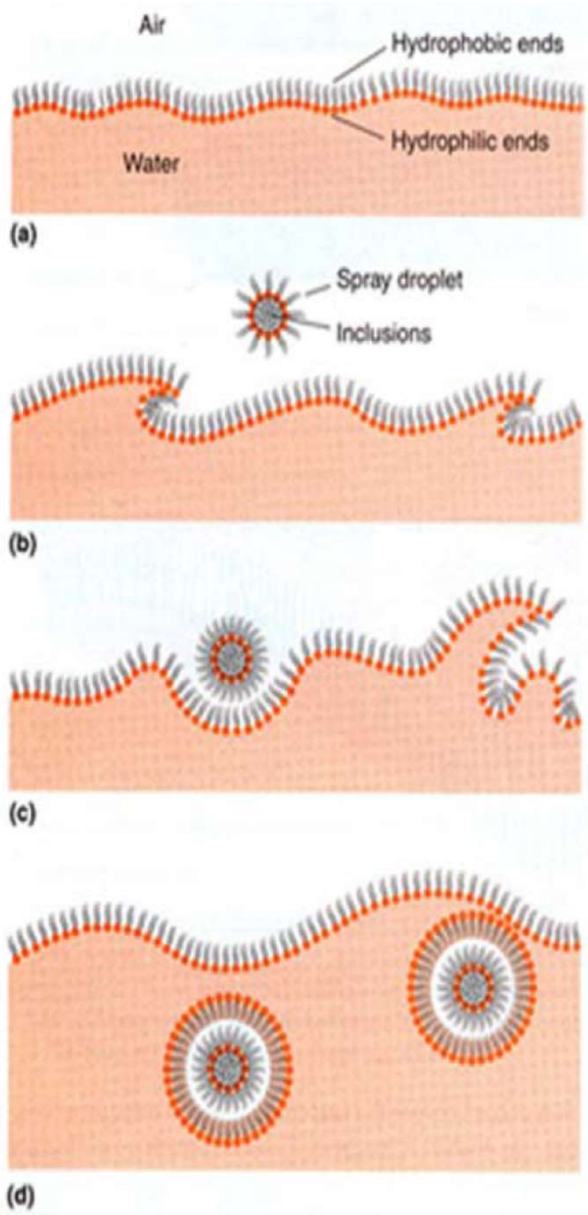
Johnston et al., *Science* 292 (2001) 1319; Robertson and Scott, *Science* 315 (2007) 1549;
Chapple, Bartel, Unrau, *RNA* 9 (2003) 1208; Nissen, Hansen, Ban, Moore, Steitz, *Science* 289 (2000) 905

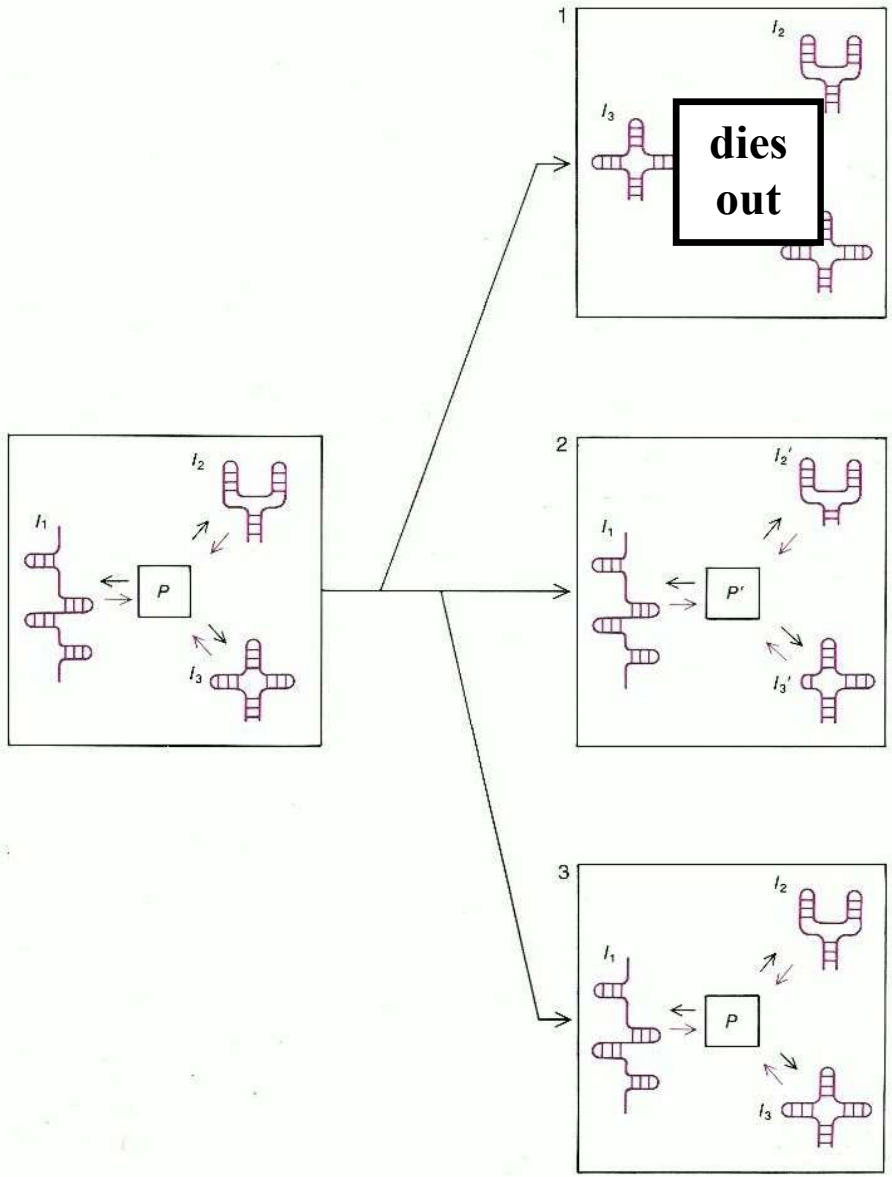
Hypercycles and Metabolism



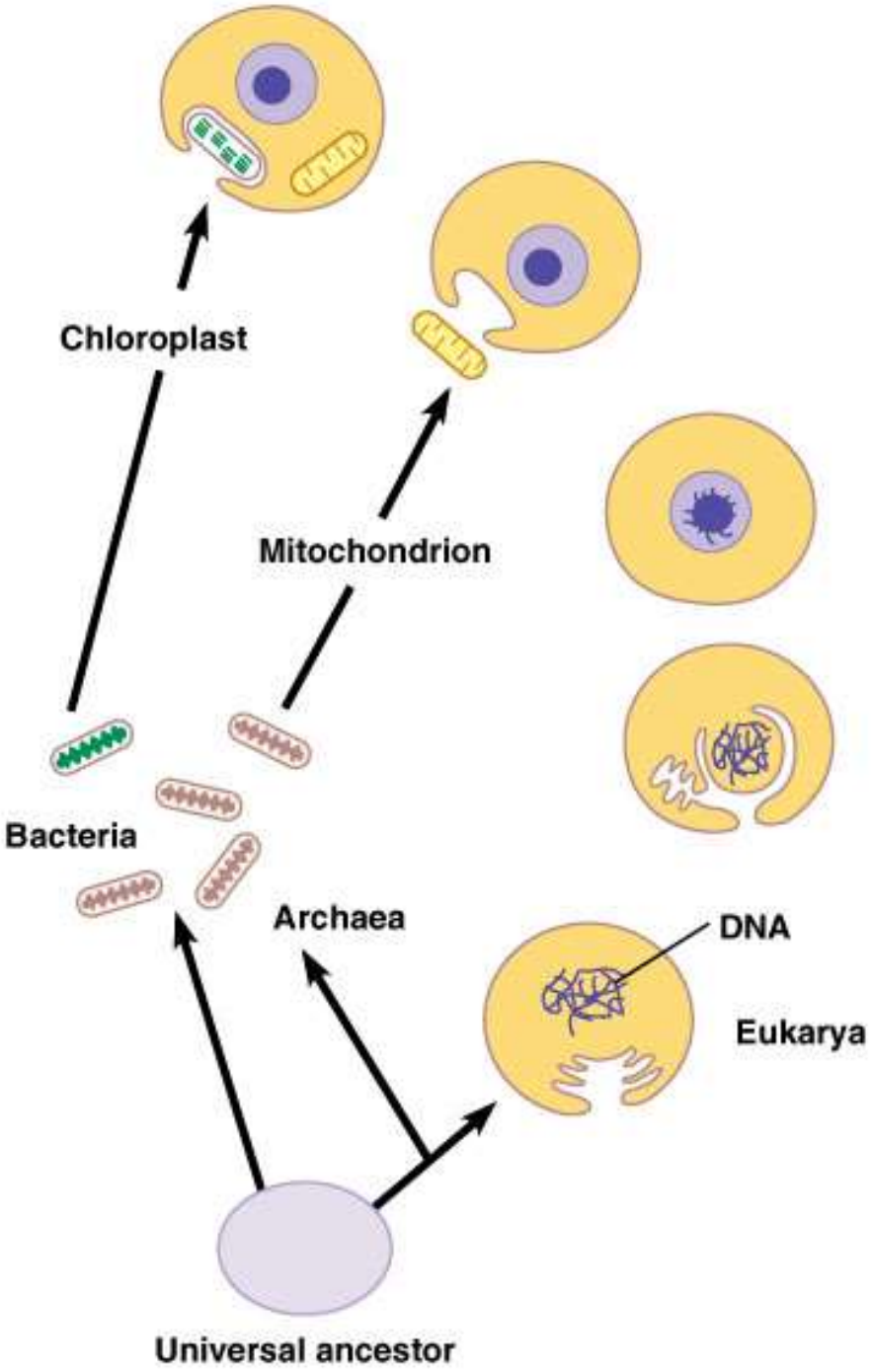
M. Eigen, W. Gardner, P. Schuster, R. Winkler-Oswatitsch, *Scientific American* 4/1981

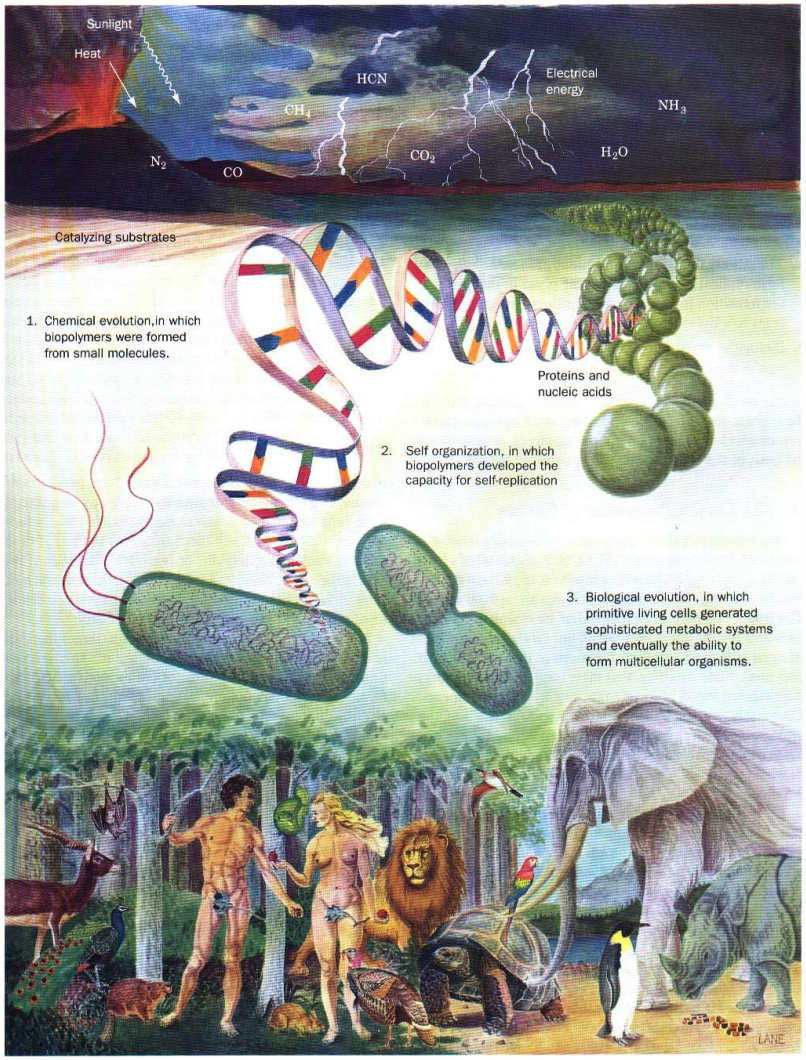
Primitive cells in the primordial world: Distinction between self and non-self





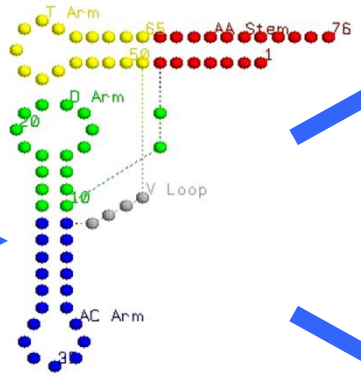
Modern eukaryotes formed through endosymbiosis



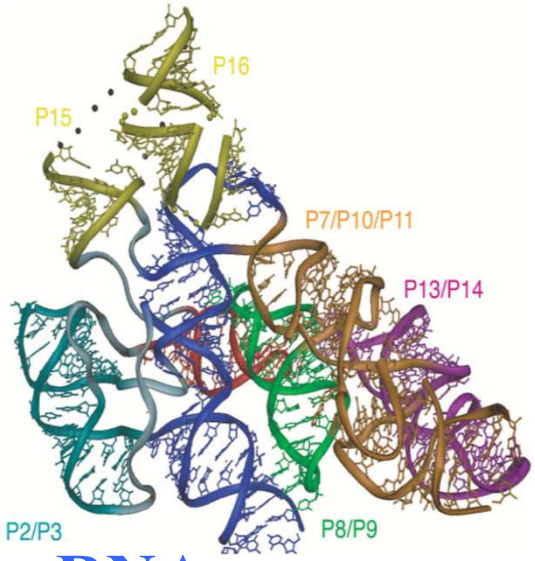


Molecularly: Transitions to an RNA-protein, then the modern DNA-RNA-protein world

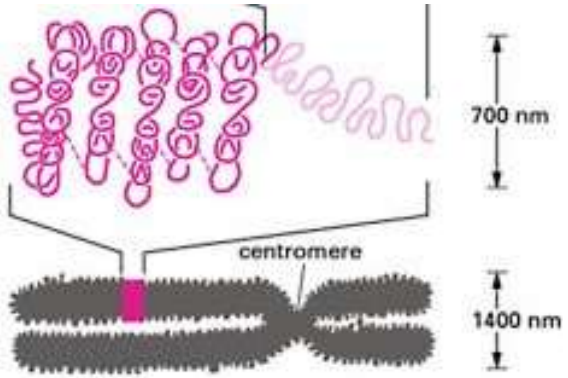
?



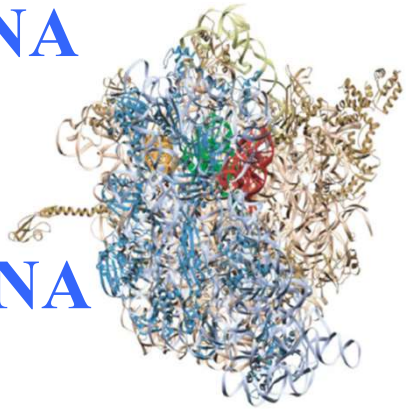
RNA



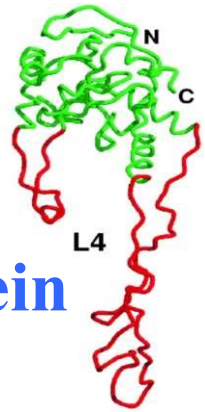
RNA



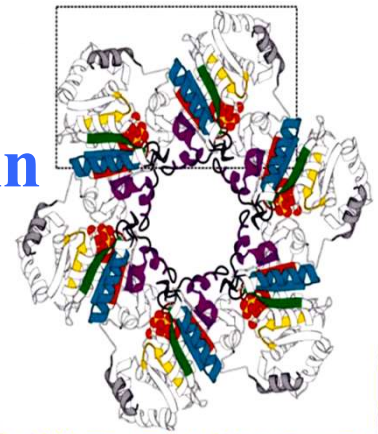
DNA



RNA



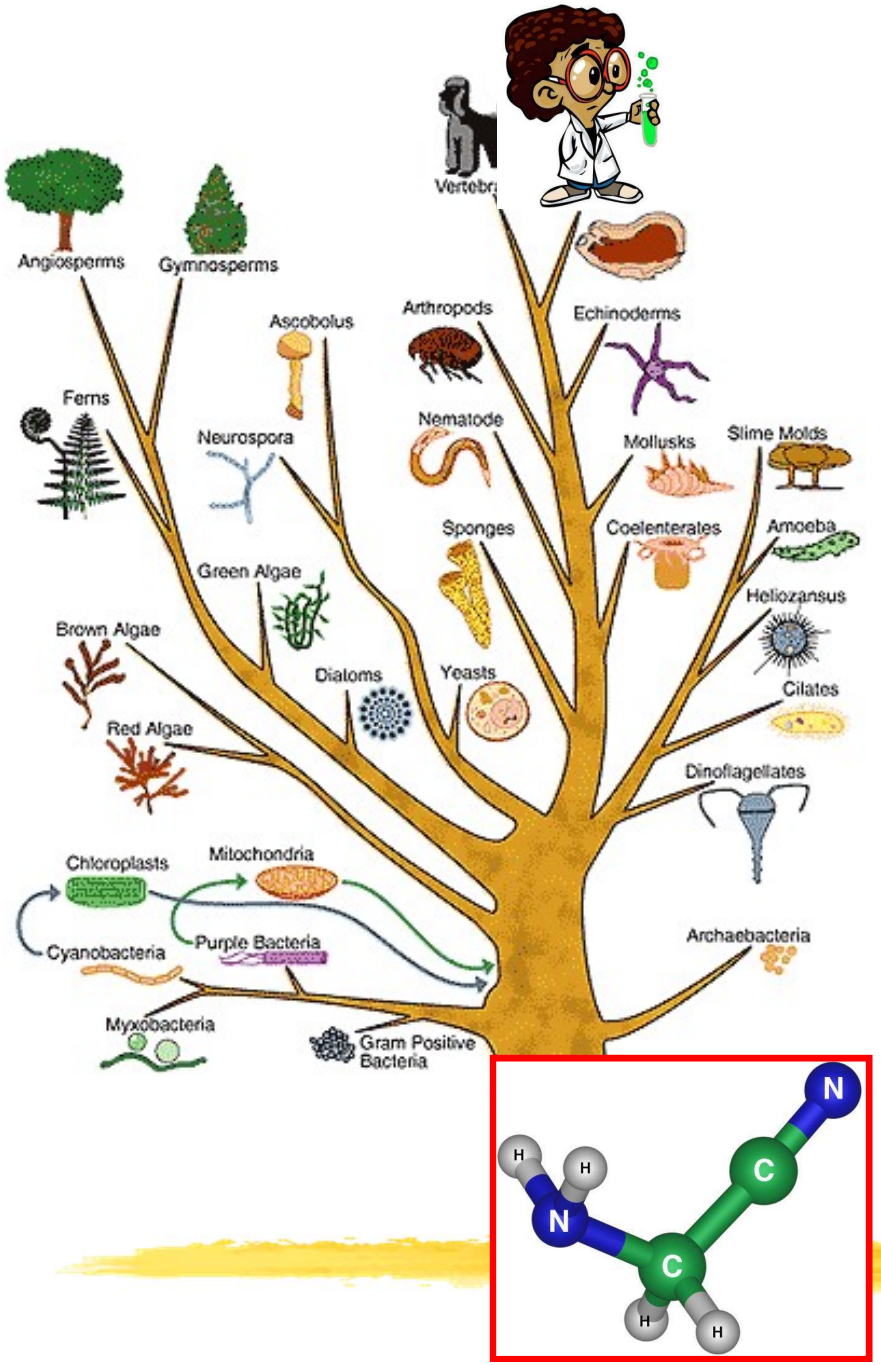
protein



protein

Pictures from: Ramakrishnan, *Cell* 108 (2002) 557; Nissen, Hansen, Ban, Moore, Steitz, *Science* 289 (2000) 905; Sawaya, Guo, Tabor, Richardson, Ellenberger, *Cell* 99 (1999) 167; Torres_Larios, Swinger, Krasilnikov, Pan, Mondragon, *Nature* 437 (2005) 584

Chemical evolution took a billion years, but left few traces



But modern biochemistry carries evolutionary "fossils" that can partially be traced back

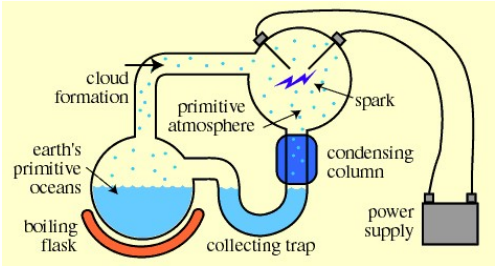
- Let's go find them!

Summary I: The force is with (Bio)Chemistry

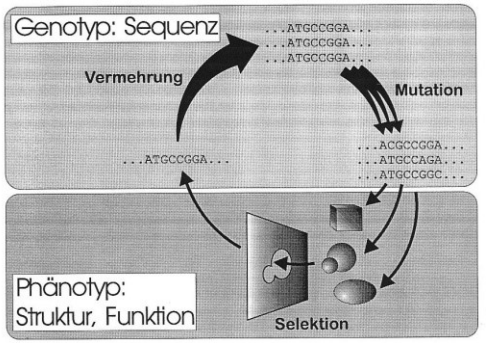
Chemistry

Summary II: Take home messages

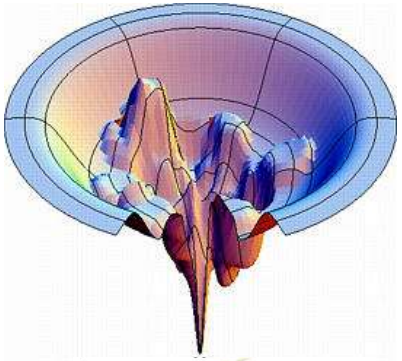
- Starting small, Nature builds ever bigger – as long as external energy sources are available



- Darwin everywhere: From Chemistry to Biology



- No such thing as a "blind watchmaker": Complex self-assembly is inevitable



- The beauty of biochemistry can be traced back to the origins