6. The origin of life

Why so fundamental is a proton-motive force in bacteria?

RNA world

- two serious problems with the RNA world
  - ribozymes are not very versatile catalysts, while minerals are
  - where comes the energy for ribozyme replication and turnover?

The idea of a primordial soup

- Stanley Miller and Harold Urey: abiotic synthesis of organic compounds
- primordial soup
- life of fermentation
- birth of autotrophs (H2S photosynthetic bacteria)
- birth of oxygen respiring bacteria

Several problems with fermentation

1. Ran out of fermentable substrates
   - There is a gap of at least several hundred million yrs
   - Life origin at least 3.85 billion yrs ago
   - Photosynthesis between 3.5 and 2.7 billion yrs go

2. Fermentation is not a primitive process
   - too complex a process requiring 12 enzymes

3. LUCA: the last universal common ancestor of all known life on earth

Classical fermentation did not exist in LUCA

Photosynthesis evolved in cyanobacteria never found in any archaea

Both the archaea and bacteria do ferment

but they do so by using different unrelated enzymes

The first cell

If proton pumping is fundamental to life, it should be present in both bacteria and archaea

Both have respiratory chains with similar components

Both share an ATPase that is basically similar in its structure and function

Respiration is far simpler than fermentation

electron transport (just a redox reaction)

a membrane

a proton pump

an ATPase

The problem of membrane

the membranes of bacteria and archaea have very little in common

meaning difference in the enzymes involved in the synthesis

Martin & Russell: LUCA could not have had a lipid membrane

inorganic membrane: a thin, bubbly layer of iron-sulfur minerals

Full metal jacket

Iron-sulfur minerals such as iron pyrites

Black smokers in the deep sea
The smoke composed of iron and hydrogen sulphide, which precipitate as iron-sulphur minerals

Iron-sulfur minerals: well-known catalyst in organic reaction and in proteins

<u>Gunter Wachtershauser, late 1980s and 1990s</u>
Suggested iron-sulfur minerals to reduce CO2 to a plethora of organic molecules
Hydrothermophiles as the most ancient groups

Supported by genetic evidence but questioned by thermodynamics problems
- dissociation of reaction products after being generated on the surface of iron-sulfur

<u>Mike Russell, late 1980s</u>
- Finding of minerals forming huge numbers of tubular structures
  - in 350 million yrs old iron-pyrites at Tynagh in Ireland
  - A possible reaction scenario in the menacing black smoker
  - Demonstrated in laboratory (Fig. 8)
- Highly probable in the points that
  - Cells are naturally chemiosmotic
  - Conduction of electrons in the bubbly membranes of iron-sulfur crystals

PART 3
Insider Deal;: the foundations of complexity

What exactly is it about the eukaryotic cell that seems to encourage the evolution of complexity?

- Mitochondria
- Once they existed, life was almost bound to become more complex

This seems to say the assignment of a forward-looking purpose

Monod in “Chance and Necessity”: biology is full of purpose and apparent trajectories

- Blind chance to a refined machines by purpose and natural selection

How to explain it?

Greater complexity demands more genes
Where do all these extra gene come from?
Large dramatic changes: non-Darwinian view (gradual evolution)

<u>The difference between bacteria and eukaryotes</u>
Bacteria: nearly unlimited biochemical diversity but no drive towards complexity
Eukaryotes: little biochemical diversity but a marvelous flowering in the realm of bodily design

Mitochondria are not simply an efficient means of generating energy

Fig. 9: 1905 Konstantine Merezhkovskii

an evolutionary tree of upside down variety

fused branches to generate a new domain of life

Cambrian explosion:

the great, and geologically sudden, proliferation of life around 560 million yrs ago

Later extinction of most of the major branches

Symbiosis: bicycle + engine = motorcycle (it is simply a Darwinian view)

Why there is no reason to evolve a motorcycle in the absence of symbiosis

Symbiosis made more profound evolutionary novelties

7. Why bacteria are simple: size & cell wall

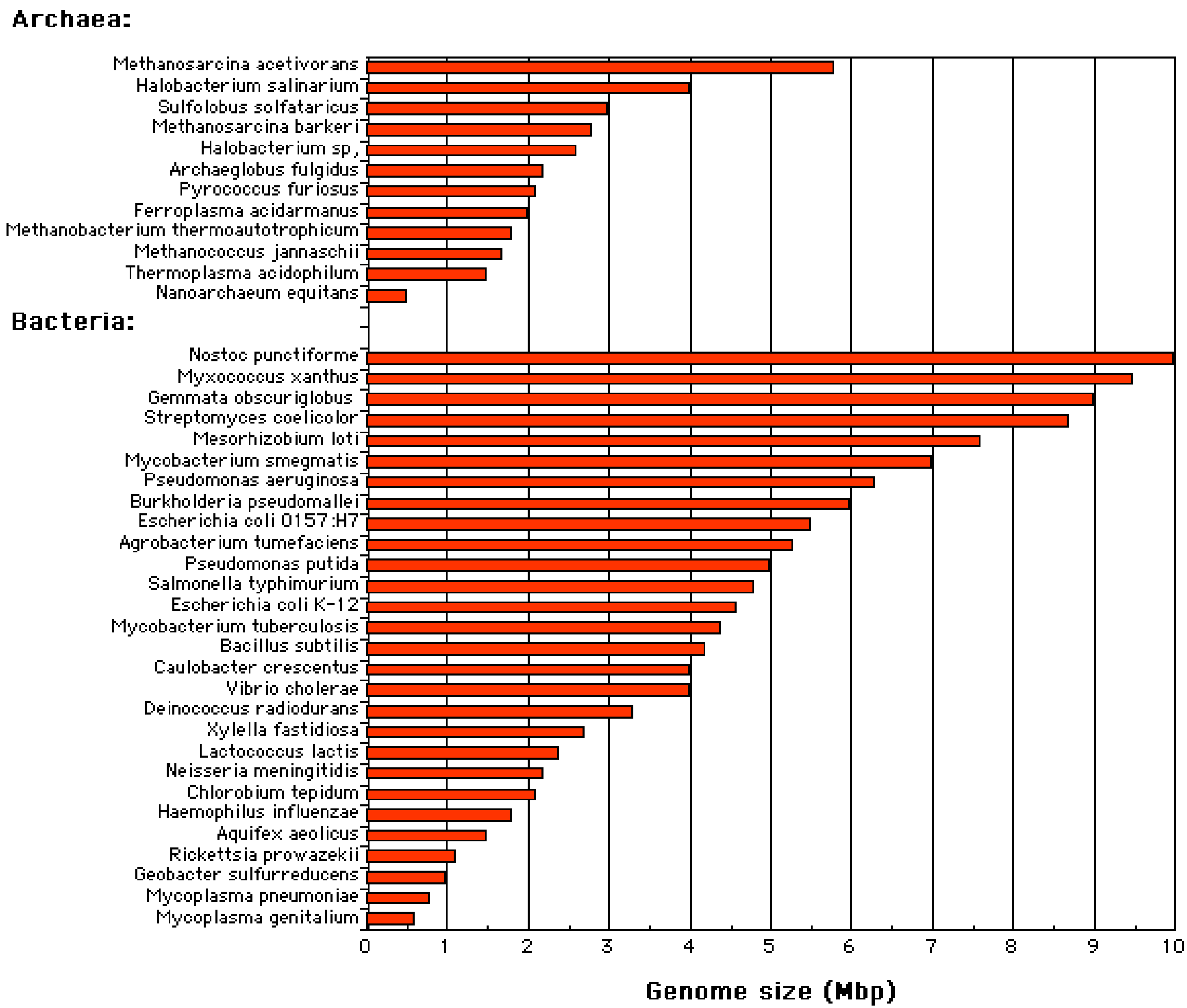
How the eukaryotes were released from a selection pressure of genome size
that stifles even the most versatile bacteria?

What determines the bacterial genome size?
The bacteria replicate fastest dominate the population
The speed of cell division is determined by DNA replication
The speed of DNA replication depends on genome size
and effective energy production

Konstantino Konstantinidis & James Tiedje
when resources are scarce but diverse
where there is little penalty for slow growth
bacteria with the largest genomes provide more chance and therefore dominate

does it mean a possibility of larger bacterial genome size comparable to those of eukaryotes?

There seems to be a limit in bacterial genome size: selected against because of time and energy



http://www.sci.sdsu.edu/~smaloy/MicrobialGenetics/topics/chroms-genes-prots/genomes.html

organism	estimated size	estimated gene number	average gene density	chromosome number
Homo sapiens (human)	2900 million bases	~30,000	1 gene per 100,000 bases	46
Rattus norvegicus (rat)	2,750 million bases	~30,000	1 gene per 100,000 bases	42
Mus musculus (mouse)	2500 million bases	~30,000	1 gene per 100,000 bases	40
Drosophila melanogaster (fruit fly)	180 million bases	13,600	1 gene per 9,000 bases	8
Arabidopsis thaliana (plant)	125 million bases	25,500	1 gene per 4000 bases	10
Caenorhabditis elegans (roundworm)	97 million bases	19,100	1 gene per 5000 bases	12
Saccharomyces cerevisiae (yeast)	12 million bases	6300	1 gene per 2000 bases	32

http://www.ornl.gov/sci/techresources/Human_Genome/faq/compgen.shtml

Gene loss as an evolutionary trajectory

Gene loss is common in bacteria

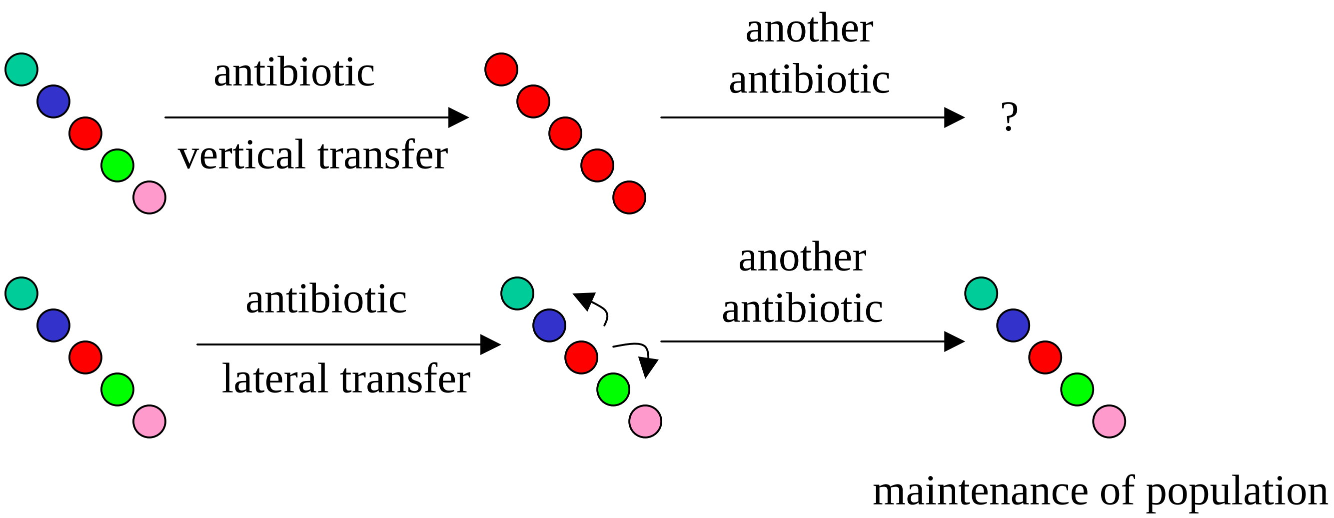
Example: *Rickettsia prowazekii*
A tiny bacterium, almost as small as a virus
A parasite
834 protein coding genes, a quarter amount of usual bacteria
- what kinds of genes are left?
- ~1/4 of the total genome are junk DNA
- gene loss is continuing process occurring today

Balancing gene loss and gain in bacteria

Gene loss: “use it or lose it”
Free-living bacteria also face a similar pressure to lose superfluous genes
A related experiment by Tibor Vellai et al., 1998
- 3 plasmids of antibiotic marker deffering in non-coding DNA
- transformed *E. coli* cells were compared for growth
- after 12 hrs in culture
- + antibiotic: the smallest plasmids outgrew 10-fold
- - antibiotic: similar growth and plasmid loss

Gene gain: lateral gene transfer
Active gain of genes compensates for gene loss
In some bacterial sp. >90% of observed variation in a population comes from lateral gene transfer
Genes can be switched so quickly and so comprehensively, obliterating all traces of ancestry
example: *Neisseria gonorrhoeae*
E. coli

Why are bacteria so open-handed with their genes?
an evolutionarily stable strategy



Continuous switching of genes: loss and gain

in order to maintain their genome size (?)

On the hand gene expansion seems to pose no problem in eukaryotes

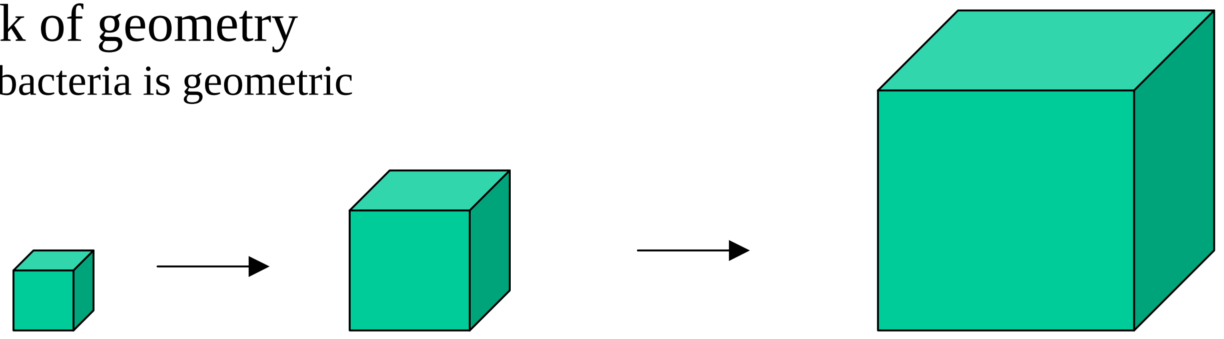
a single-celled Amoeba dubina has 670 billion bp genome

Tibor Vellai & Gabor Vida, 1999

bacteria are limited in their physical size, genome content, and complexity,
because bacteria are forced to respire across their external cell membrane

The stumbling block of geometry

The limitation for bacteria is geometric



Size	1 µm	2 µm	4 µm
Surface area	6 µm2	24 µm2	96 µm2
Volume	1 µm3	8 µm3	64 µm3
volume/surface area	6/1 = 6	24/3 = 3	96/64 = 1.5

As bacteria become larger their respiratory efficiency declines hyperbolically

Surface area: the external membrane used for generating energy & absorbing nutrients

Volume: the mass of cell using up the available energy

The problem of decreasing volume/surface area

may be overcome by

changing cell shape to rod form (larger surface area to volume ratio)

folding the membrane into sheets or villi (Fig. 10)

there may be a limit because of complexity

Thiomargarita namibeienses: http://microbewiki.kenyon.edu/index.php/Thiomargarita

How to lose the cell wall without dying

Loss of cell wall means loss of proton gradient

examples

Mycoplasma: mostly parasites (M. genycoplasma has fewer than 500 genes)

No genes for oxidative respiration

Thermoplasma: extremophile archaea living in hot vinegar

Pumping out protons by respiration

Smallest non-parasitic genome encoding 1500 genes

The genome complexity is determined by their need to generate energy across the outer cell membrane

Why insider dealing pays

Mitochondria: internalization of energy generation

- Providing a chance to be free from cell wall
- Exposure of cell membrane provided other tasks such as signaling, movement, phagocytosis
- The most important: releasing from the geometric constraints
- Internal expansion of membranes by increasing the number of mitochondria
- 2 billion yrs ago sudden appearance of large eukaryotic cells in the fossil record

- Birth of a large energetic cell: overcoming the energy barrier to being larger
- Don't need to spend time replicating its DNA to stay ahead of the competition
- hunter-gatherers and settlers: which can maintain a large population?

- Eukaryotic life style: predator
- Predation tends to drive evolutionary arms races
- Bacteria can lose their cell wall but have never developed phagocytosis

Bacterial internalization of energy production

- folding the membrane into sheets or villi (Fig. 10)
- *Nitrosomonas* and *Nitrosococcus*
- Infolded large periplasmic compartments
- Why did they stop to form a full compartment

Assignments (until 10/27/06)

Powerpoint slides about

1. Iron-sulfur minerals (pyrites)
2. Cambrian explosion