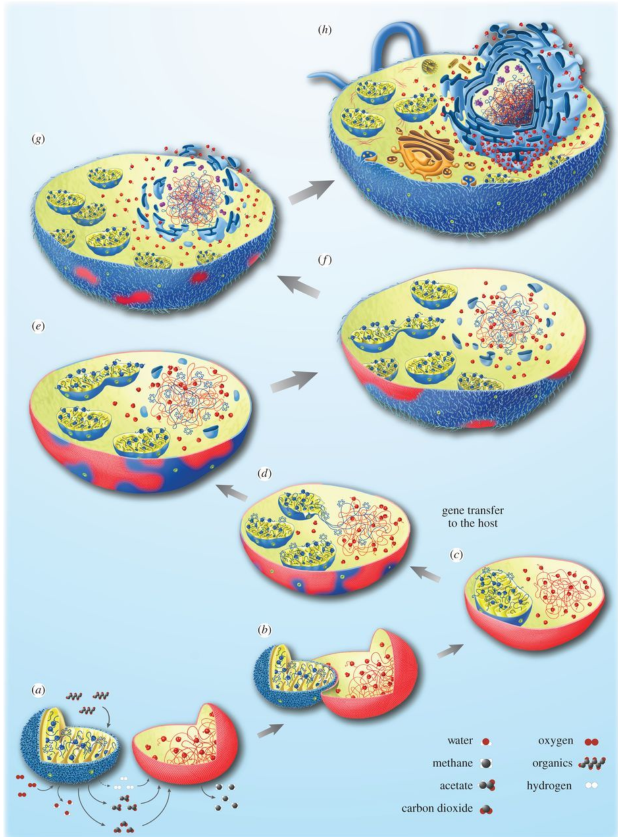

Evolution of Eukaryotes

Course Project in CL 717, Chemical Department, IITB

Prabhat Ranjan

23/11/2018

Introduction

The origin of Eukaryotes was a major singular step in evolution. The origin of life on earth goes back to around 4 billion year and life forms were morphologically similar for ~2 billion year. This change in structure and complexity happens with the sudden evolution of Eukaryotic cells. Very less is known about the intermediate steps in the course of evolution. Eukaryotic cells are fundamentally different from those of bacteria and archaea at almost every level of organization, starting with their physical size. The earliest common Eukaryotic ancestor already have most of the modern Eukaryotic features as nucleus and other endomembrane system organelles.
The most widely accepted hypothesis is of Endosymbiosis, in which a bacteria is engulfed by an Archaea. They formed a symbiotic relationship in which host Archaea provide a stable environment and food for bacteria while bacteria provides energy to the symbiotic system. It later evolved into a eukaryotic cell where bacteria assumes the role of mitochondria and Archaea becomes the cell. This transition from a symbiotic relation to complete eukaryotic cell happened in a series of evolutionary steps. Since there are no intermediates or fossils, which suggests this transition had happened very quickly in evolutionary timescale.

Steps Involved

This project will look at the time interval elapsed between the engulfment of bacteria and the formation of Nucleus inside the cell.

1. Archaea engulfing a bacteria
2. Number of bacteria grows inside the archaea host
3. Bacteria started to shed its genes to host genome.
4. Parasitic genes from Bacteria bombarded the host genome
5. Formation of split genes and spliceosome
6. Development of nucleus

STEP 1. Archaea engulfing a bacteria

Modern eukaryotic cell has proteins which are present in both Archaea and bacteria exclusively which suggest a chimeric origin of Eukaryote. It could be explained with the symbiotic relationship between bacteria inside an Archaeal host. This is believed completely accidental.

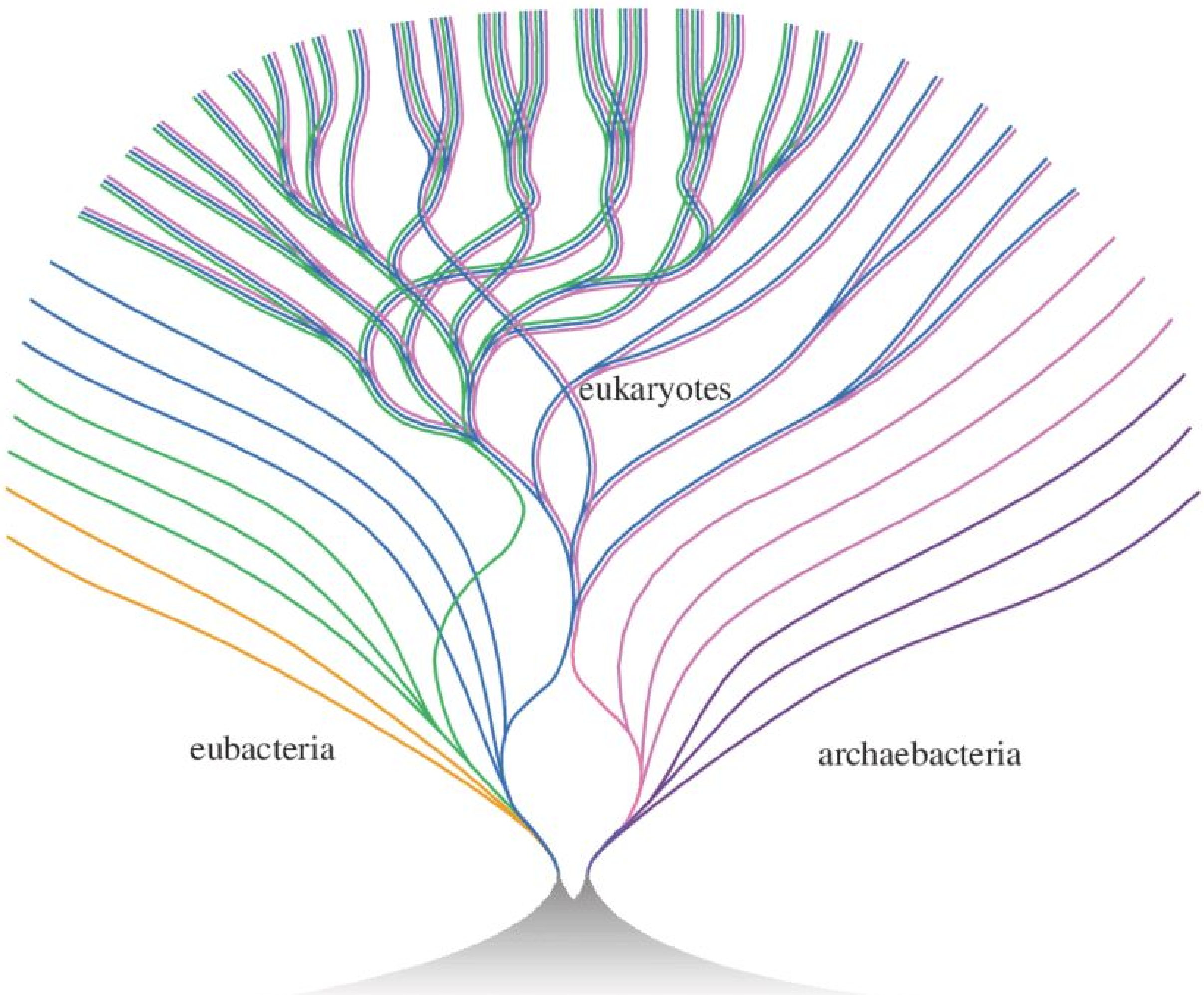

Figure 5 A tree of life drawn by Bill Martin in 1998, reflecting whole genomes. The tree shows the chimeric origin of eukaryotes, in which an archaeal host cell acquired bacterial endosymbionts that evolved into mitochondria; and the later acquisition of chloroplasts in Plantae.

STEP 2. The number of bacteria grows inside the Archaeal host cell:

Since the bacteria found itself in a relatively stable environment the number of bacterial cell per host began to increase rapidly which is only stopped by the amount of food material archaea could supply to the bacteria.

STEP 3. Bacteria started to shed its genes

Since the bacteria have a relatively stable environment now it could easily discard many genes which are no longer needed into the cytoplasm of the host.
Many of these genes would be picked by the host genome and the size of genome began to increase.
Further many of the common genes which are not needed for the urgent operation of the bacterial cell were also incorporated to the host genome and the size of the host genome continues to grow while the genetic size of bacteria continues to decrease.
The bacteria started to rely upon the host proteins and machinery for most of its function.

STEP 3. Bacteria started to shed its genes

The parasitic DNA molecules from the bacteria started to incorporate itself in host genome in multiple copies which increase the genetic load of the host cells. But this load of coping more genetic material can be balanced due to extra energy generated by individual bacterial cells which now has more energy per gene.

STEP 4. The Parasitic DNA attacks the host genome:

The bombardment of parasitic DNA resulted into the formation of split genes which require spliceosome to form the correct mRNA and form correct protein.

STEP 6. Formation of nucleus

The speed of spliceosome to cut and paste the RNA is much slower than the speed of translation by ribosomes hence there is a need for the separate compartmentalization inside the cell where spicing of a mRNA could be done in absence of Ribosomes. Hence it provided a path for the formation of the nucleus, which separated the mRNA from the cytoplasm.

Modelling endosymbiosis

There are many hypotheses which try to explain the origin of mitochondria inside the cell which is a crucial stage in the evolution of Eukaryotes.

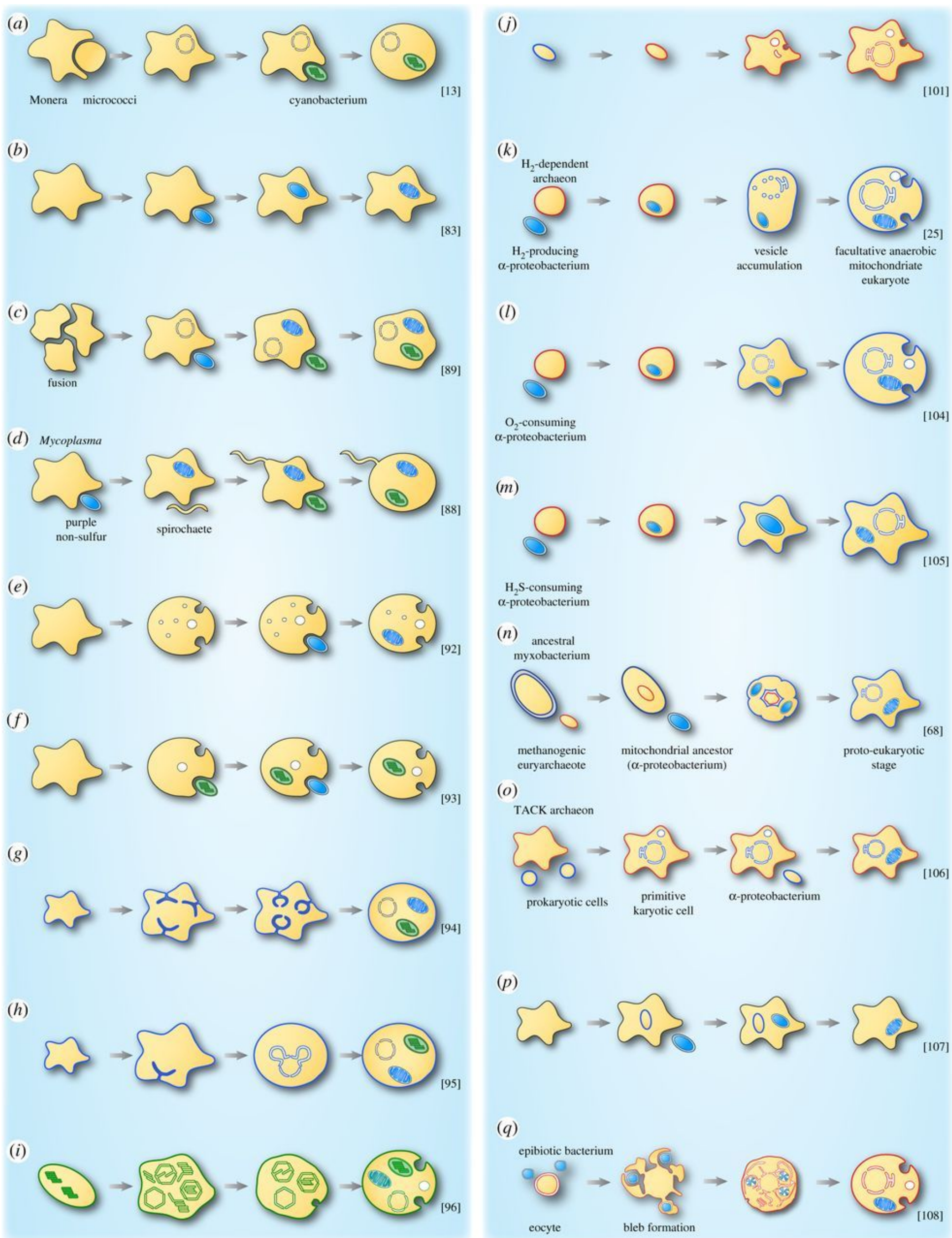

Fig. Models describing the origin of mitochondria and/or chloroplasts in eukaryotes. (a–q) Schematic of various models accounting for the origin of mitochondria and/or chloroplasts. Archaeal cells/membranes are represented with red, while blue indicates eubacterial cells/membranes. Black membranes are used when the identity of the cell is not clear and green is used for cyanobacterial derived cells/membranes

Of these hypothesises, the most popular for endosymbiosis is **Hydrogen hypothesis.** It was proposed by **William F. Martin and Miklós Müller in 1998.**

According to this theory:

1. A host that acquired the mitochondria was a hydrogen dependent archaeon, similar to modern methanogens and which uses carbon dioxide and methane as a byproduct.
2. The modern mitochondria are once a facultative anaerobic bacteria which produces carbon dioxide and hydrogen as the byproduct for the anaerobic respiration.
3. There was a symbiotic relationship between the host and the symbiont based on the need of the host for hydrogen. (anaerobic syntropy).

The syntropy was a crucial step in the development of endosymbiosis since it explains the evolutionary pressure for a close association between the host and endosymbiosis. And since it doesn't require phagocytosis, which is not compatible with the membrane which an archean cell have, it is more acceptable.

The Idea here is to model the steps which lead to the endosymbiosis of the bacterial cell and try to explain whether the endosymbiosis will be beneficial for the cell.

Currently, no mathematical model was developed for this purpose. The only thing that could be said that the bacterial cell and the archaeal cell will try to maximise the surface area of contact for the efficient exchange of nutrients.

Assuming that the flux of material from one cell into the environment is constant and hence the concentration of material will decrease once we go away from the cell in the radial direction. It makes sure that the two cell in a syntropic relation must at least remain in contact of each other, for maximum gain of nutrients.

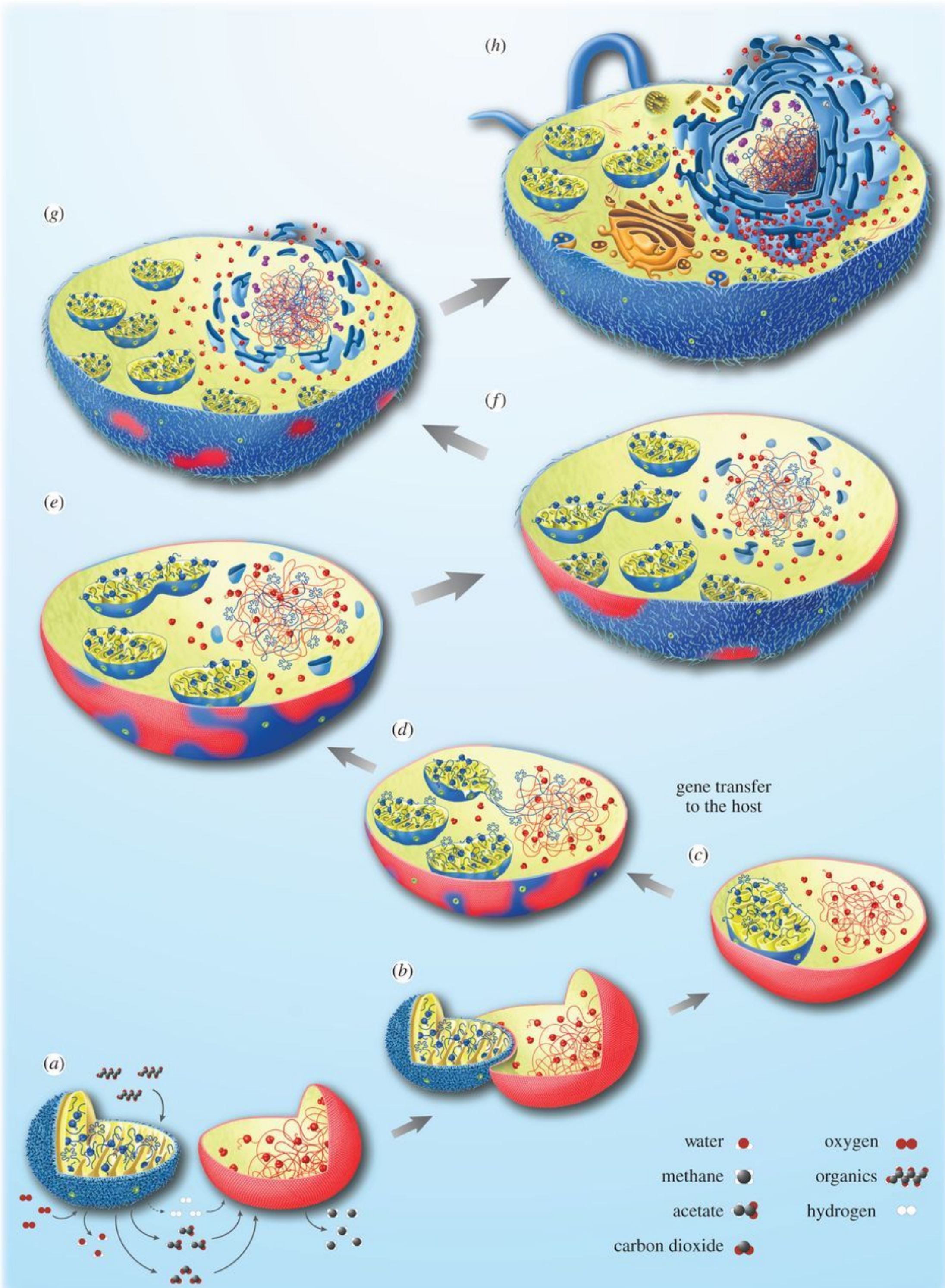

Fig.

Mitochondrial origin in a prokaryotic host. (a–h) Illustrations for various stages depicting the transition of an H2-dependent archaeal host (in red) and a facultatively anaerobic α-proteobacterium (in blue) to a eukaryote

References

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