Don’t touch those dials!

How microbes hardwired Earth for a post-human world

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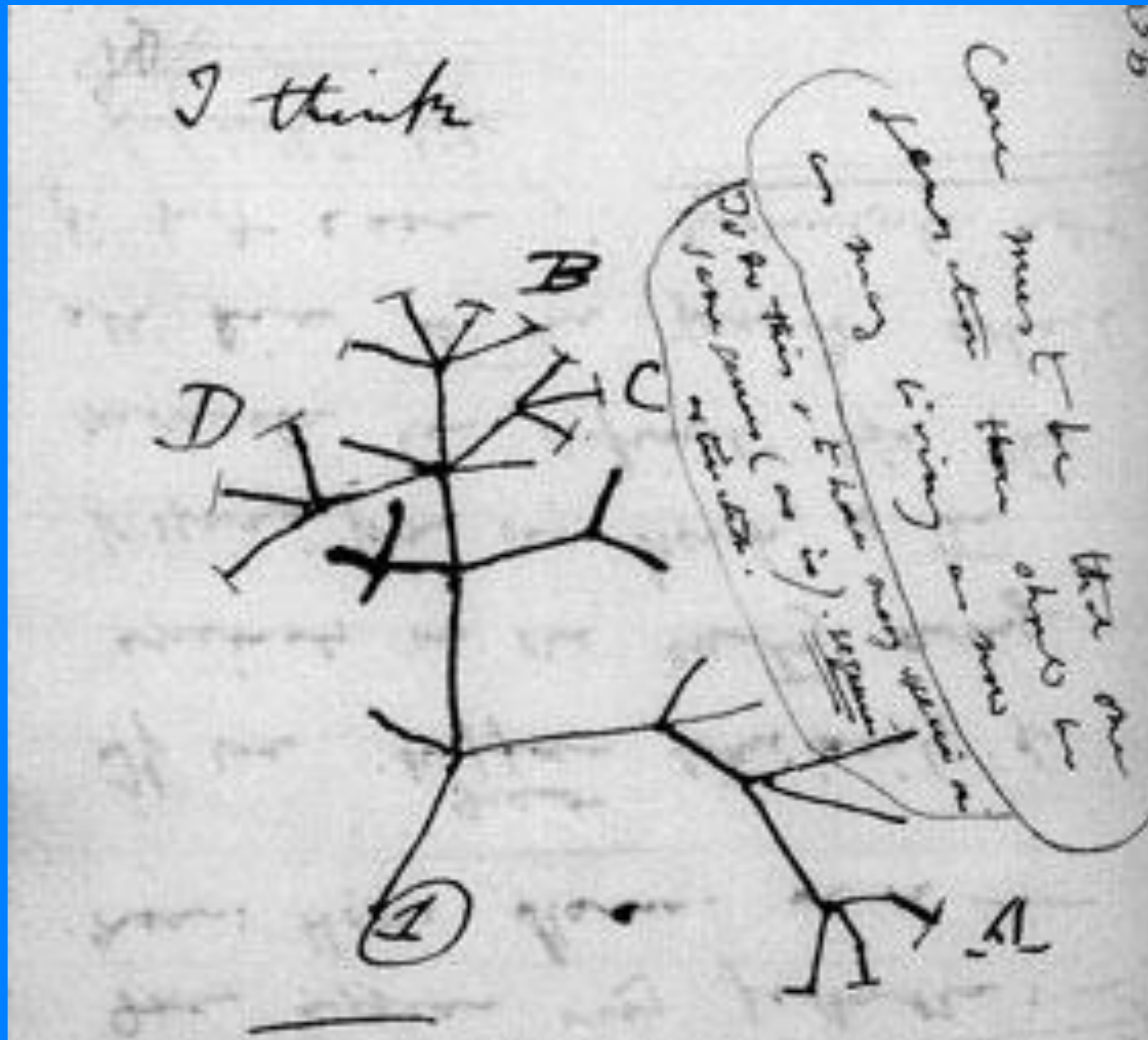
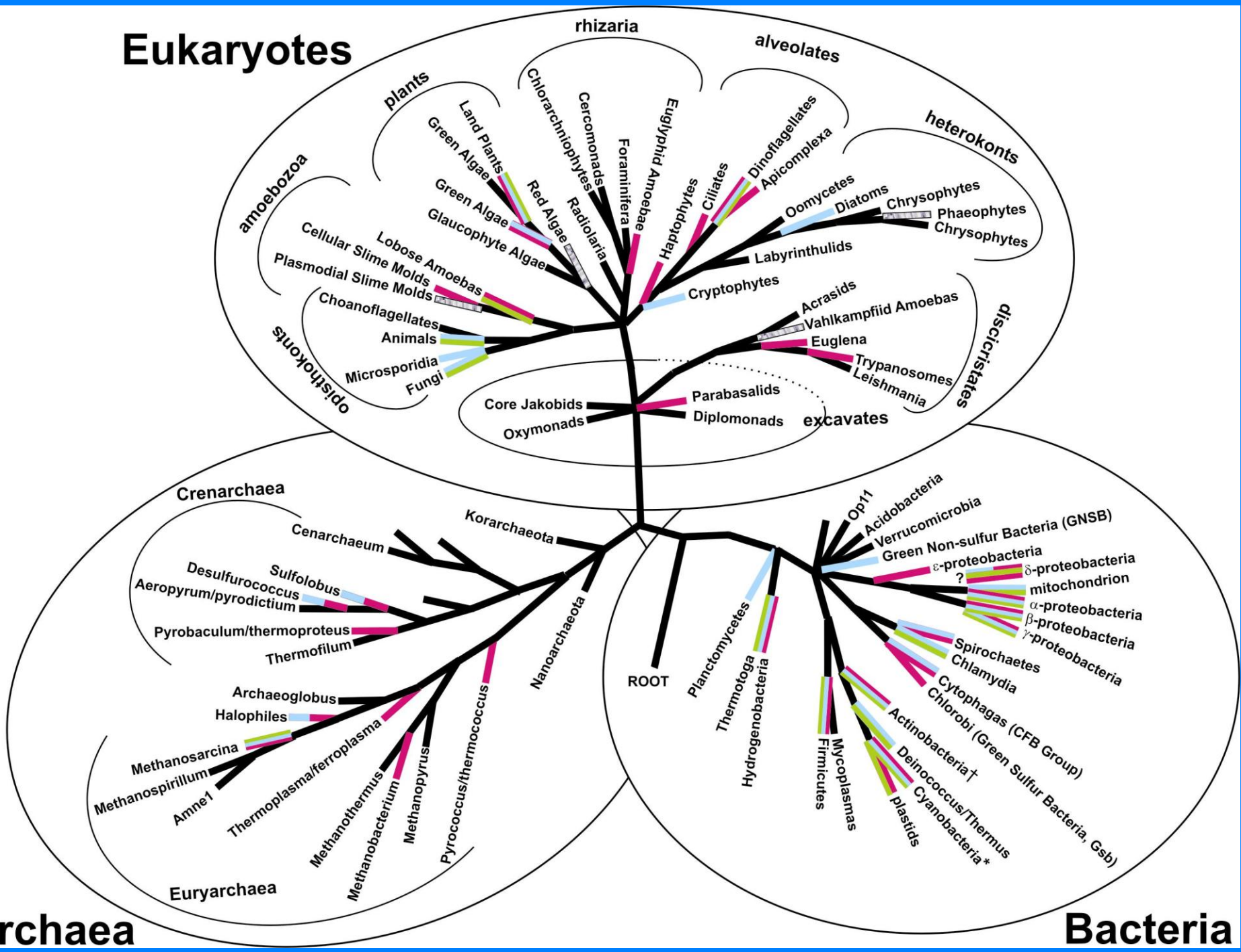
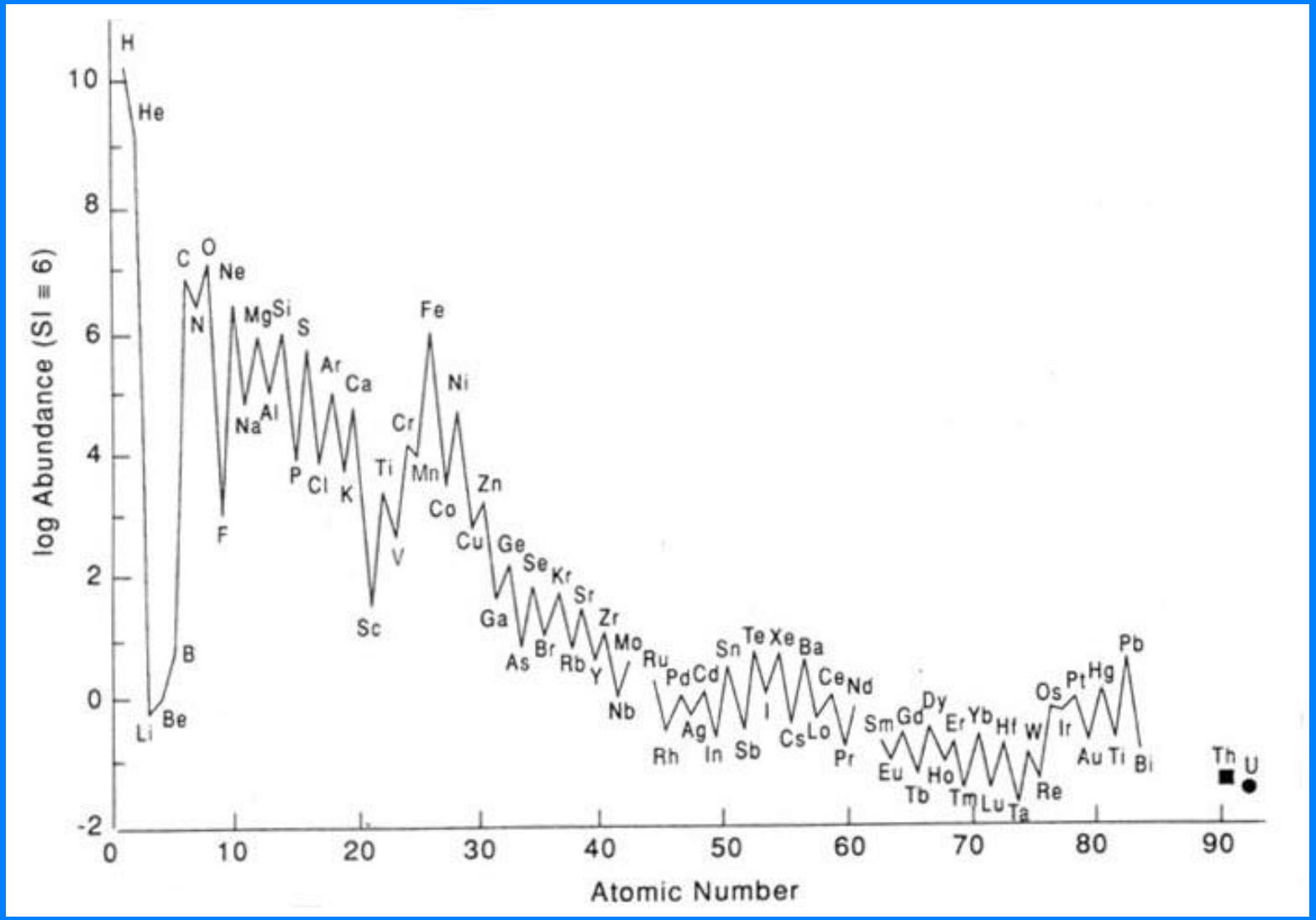

I think
B
C
D
1
A


Eukaryotes
rhizaria
alveolates
plants
heterokonts
amoebozoa
Chlorarchniophytes
Cercomonads
Foraminifera
Euglyphid Amoebae
Land Plants
Green Algae
Red Algae
Radiolaria
Haptophytes
Ciliates
Dinoflagellates
Apicomplexa
Oomycetes
Diatoms
Chrysophytes
Phaeophytes
Chrysophytes
Green Algae
Glaucophyte Algae
Labyrinthulids
Lobose Amoebas
Cellular Slime Molds
Plasmodial Slime Molds
Cryptophytes
Choanoflagellates
Animals
Microsporidia
Fungi
opisthokonts
Acrasids
Vahlkampfiid Amoebas
Euglena
Trypanosomes
Leishmania
discristates
Core Jakobids
Oxymonads
Parabasalids
Diplomonads
excavates
Crenarchaea
Korarchaeota
Cenarchaeum
Desulfurococcus
Sulfolobus
Aeropyrum/pyrodictium
Pyrobaculum/thermoproteus
Thermofilum
Archaeoglobus
Halophiles
Methanosarcina
Methanospirillum
Amne1
Thermoplasma/ferroplasma
Methanothermus
Methanobacterium
Methanopyrus
Pyrococcus/thermococcus
Nanoarchaeota
Euryarchaea
ROOT
Planctomycetes
Thermotoga
Hydrogenobacteria
Op11
Acidobacteria
Verrucomicrobia
Green Non-sulfur Bacteria (GNSB)
ε-proteobacteria
?
δ-proteobacteria
mitochondrion
α-proteobacteria
β-proteobacteria
γ-proteobacteria
Spirochaetes
Chlamydia
Cytophagas (CFB Group)
Chlorobi (Green Sulfur Bacteria, Gsb)
Actinobacteria†
Deinococcus/Thermus
Cyanobacteria*
plastids
Mycoplasmas
Firmicutes
Archaea
Bacteria


log Abundance (Si ≡ 6)
10
8
6
4
2
0
-2
0
10
20
30
40
50
60
70
80
90
Atomic Number
H
He
Li
Be
B
C
N
O
Ne
F
Na
Mg
Al
Si
P
S
Cl
Ar
K
Ca
Sc
Ti
V
Cr
Mn
Fe
Co
Ni
Cu
Zn
Ga
Ge
As
Se
Br
Kr
Rb
Sr
Y
Zr
Nb
Mo
Ru
Rh
Pd
Ag
Cd
In
Sn
Sb
Te
I
Xe
Cs
Ba
La
Ce
Pr
Nd
Sm
Eu
Gd
Tb
Dy
Ho
Er
Tm
Yb
Lu
Hf
Ta
W
Re
Os
Ir
Pt
Au
Hg
Tl
Pb
Bi
Th
U

The origin of life is the invention of non-equilibrium redox chemistry that involves five of the
The “Big Six”

H, C, N, O, P and S

And at least 54 other “trace elements”

Life is Electric

- All organisms derive energy for growth and maintenance by moving electrons from a substrate to a product.
- All substrates and products must ultimately be cycled.
- Biological processes are paired (e.g., photosynthesis and respiration)

Microbes are like lawyers –they cannot exist alone

The electron “marketplace”

Maintaining life on a planet requires recycling of electrons

What were the sources and sinks of electrons in the Archean and what are they today?

The major sources of electrons during the Archean were

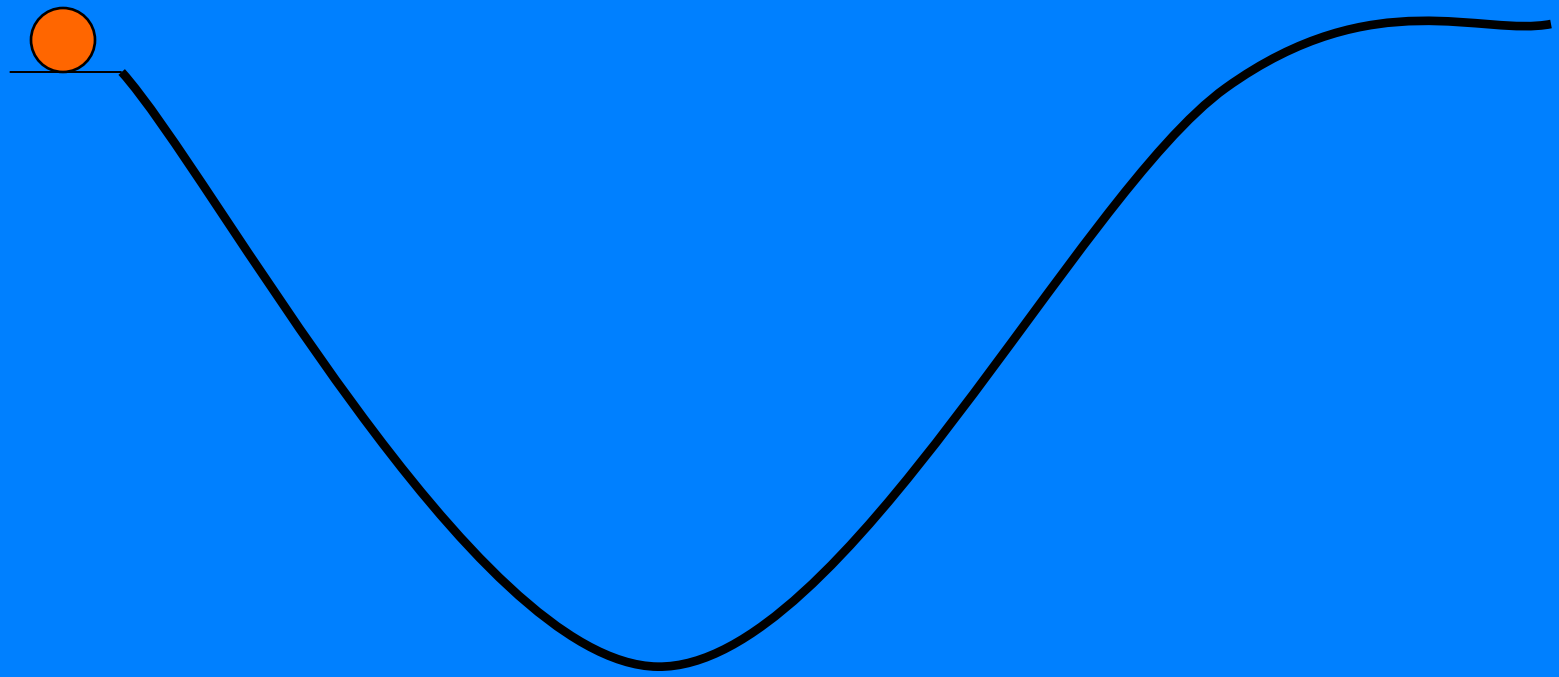
H_2S, Fe(II), and H_2

The major source of electrons today is

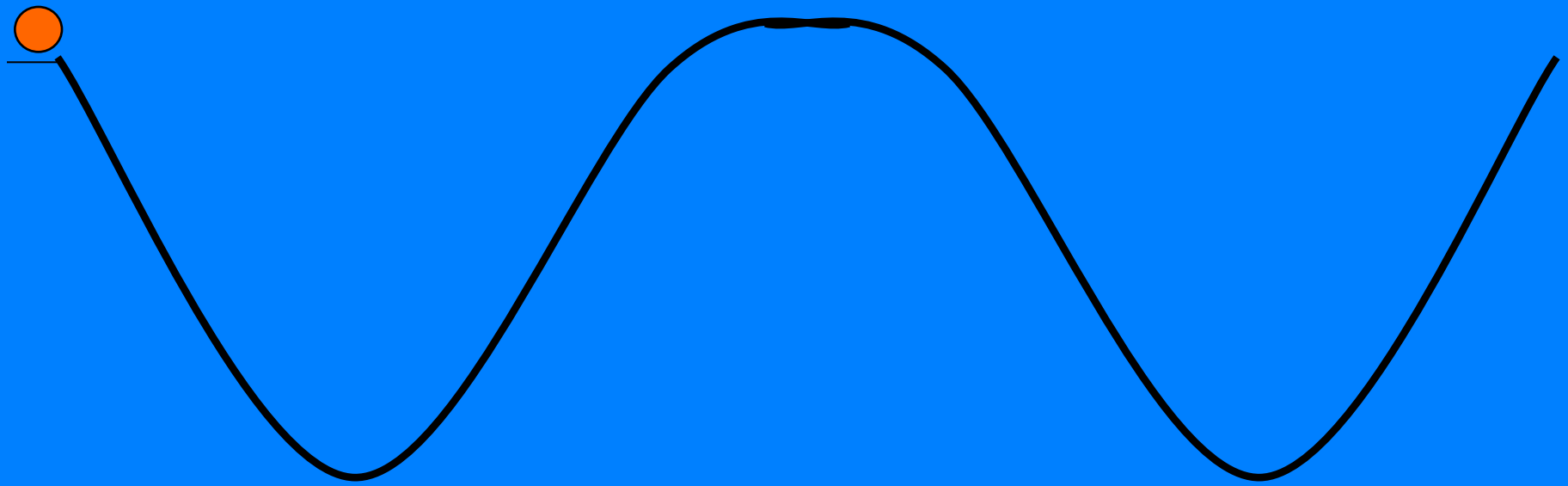
LIQUID WATER

(H_2O)

The “Ball in the Bowl” metaphor for the first (R&D) half of Earth’s History

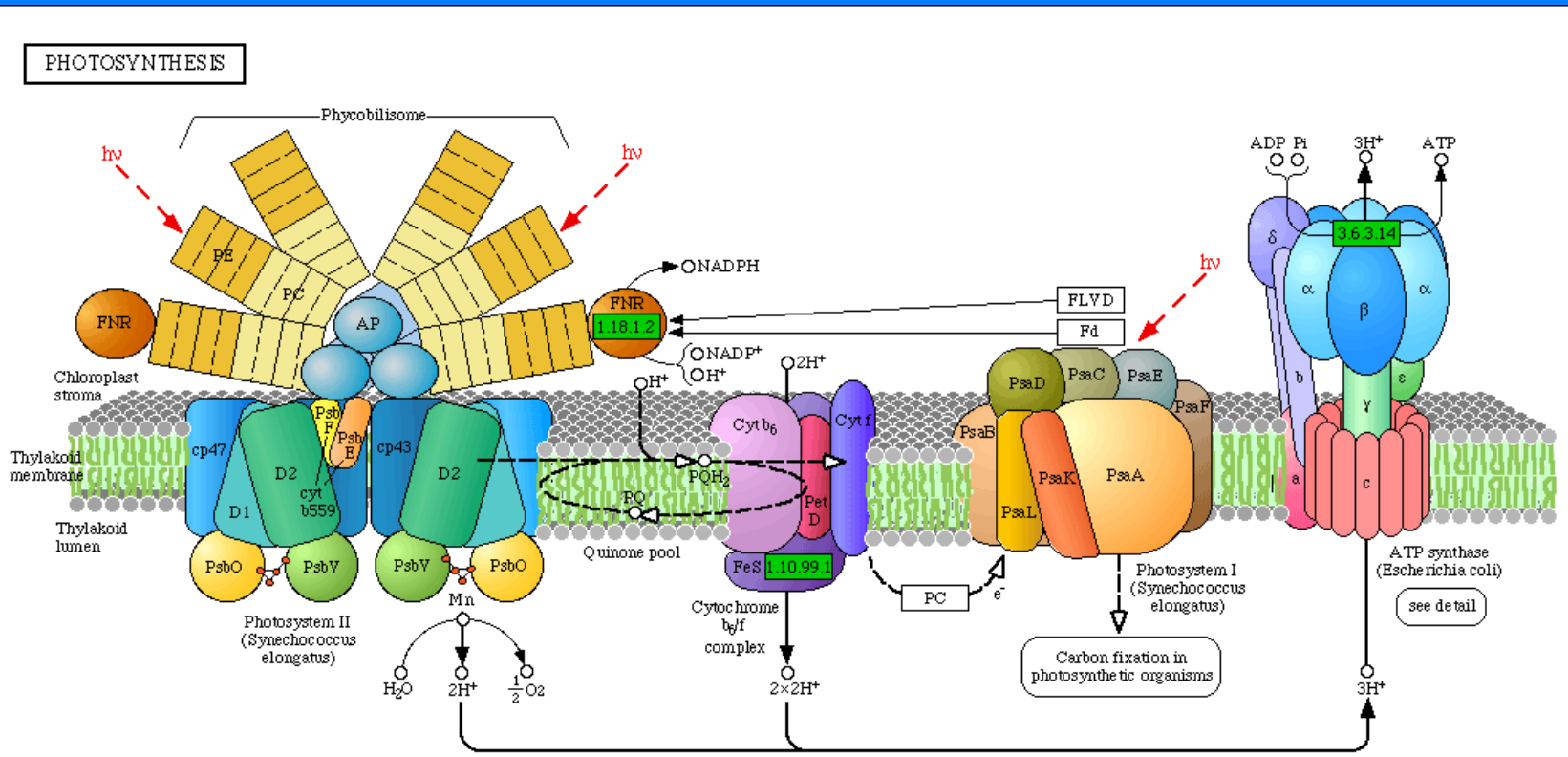


The “Big Flip” into the second half of Earth’s history – why did Earth become oxidized anyway?



The evolution of nannomachines

The fundamental problem in origins of life - evolution of energy transduction before information? Or vice versa?



Photosystem II

D1	D2	cp43	cp47	cyt b559			
PsbA	PsbD	PsbC	PsbB	PsbE	PsbF		
PsbL	PsbJ	PsbK	PsbM	PsbN	PsbH	PsbT	PsbI
PsbO	PsbP	PsbU	PsbV	PsbW	PsbX	PsbY	PsbZ

Photosystem I

PsaA	PsaB	PsaC	PsaD	PsaE	PsaF	PsaH	PsaI
PsaJ	PsaK	PsaL	PsaM	PsaN	PsaX		

Cytochrome b6/f complex

PetB	PetD	PetA	PetC	PetL	PetM	PetN	PetG	PetE	PetF	PetH

Allophycocyanin (AP)

ApcA	ApcB	ApcC	ApcD	ApcE	ApcF

Phycocyanine (PC)

CpcA	CpcB	CpcC	CpcD	CpcE	CpcF	CpcG

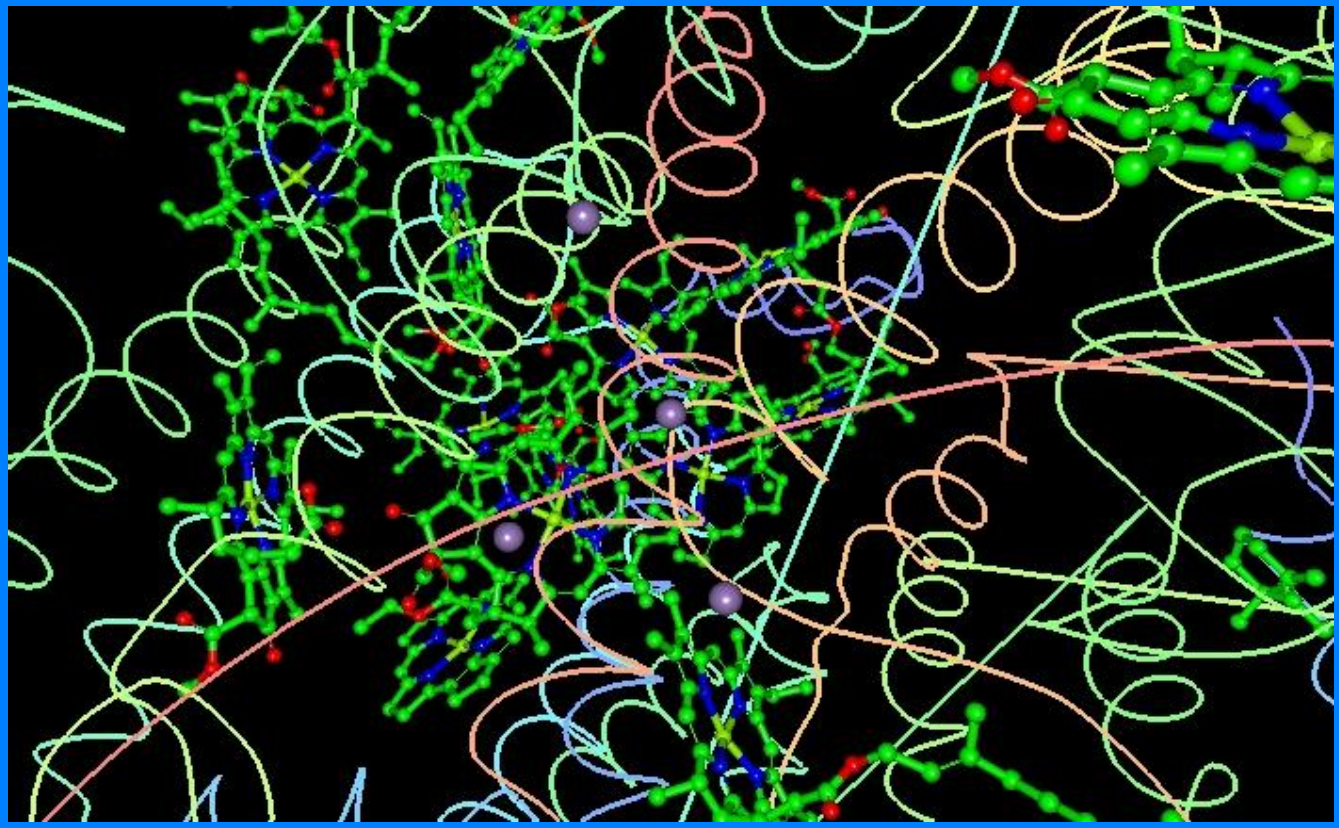
Phycoerythrin (PE)

PecA	PecB	PecC	PecE	PecF

00195 7/16/03

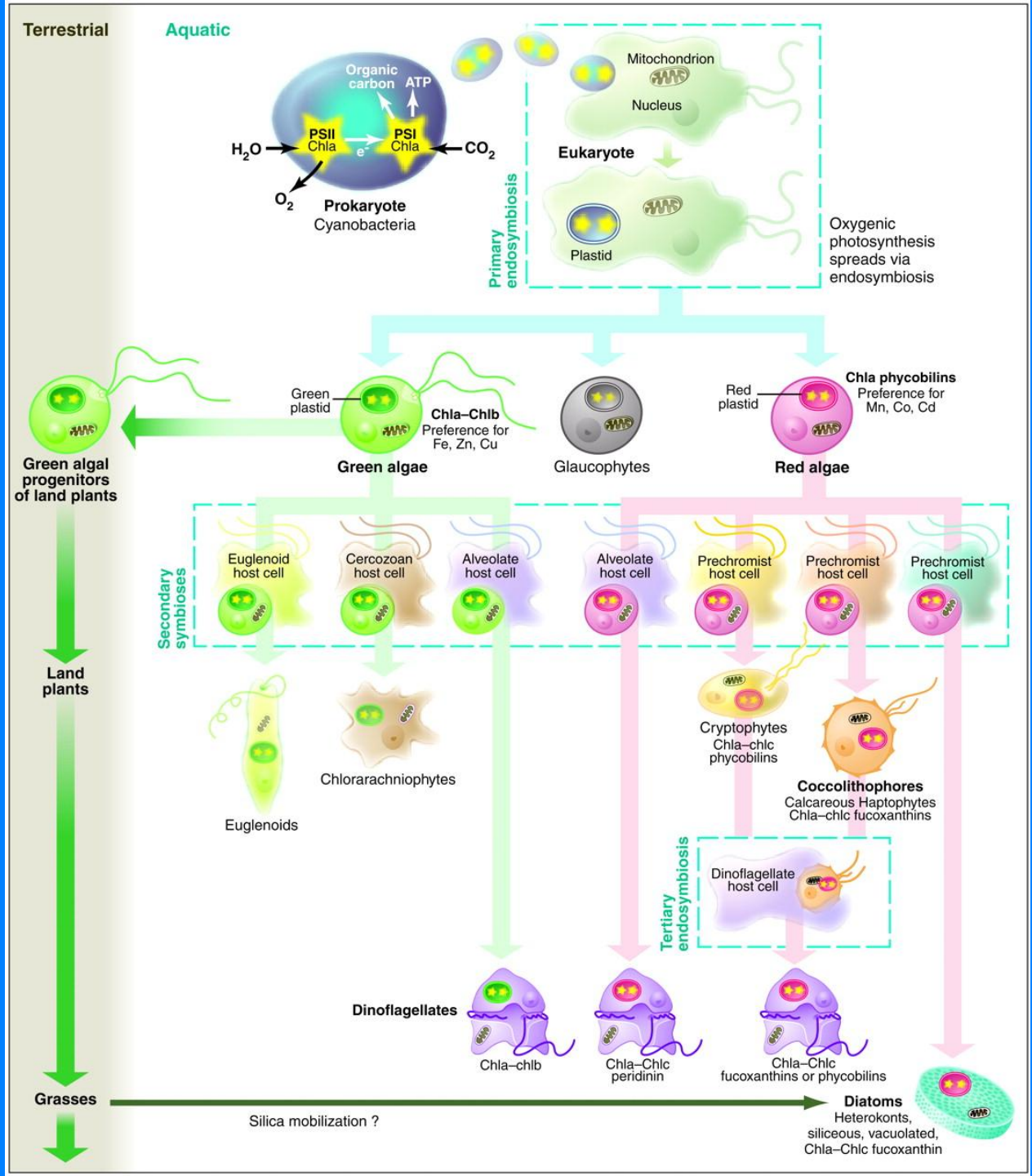
PSII type Reaction Center

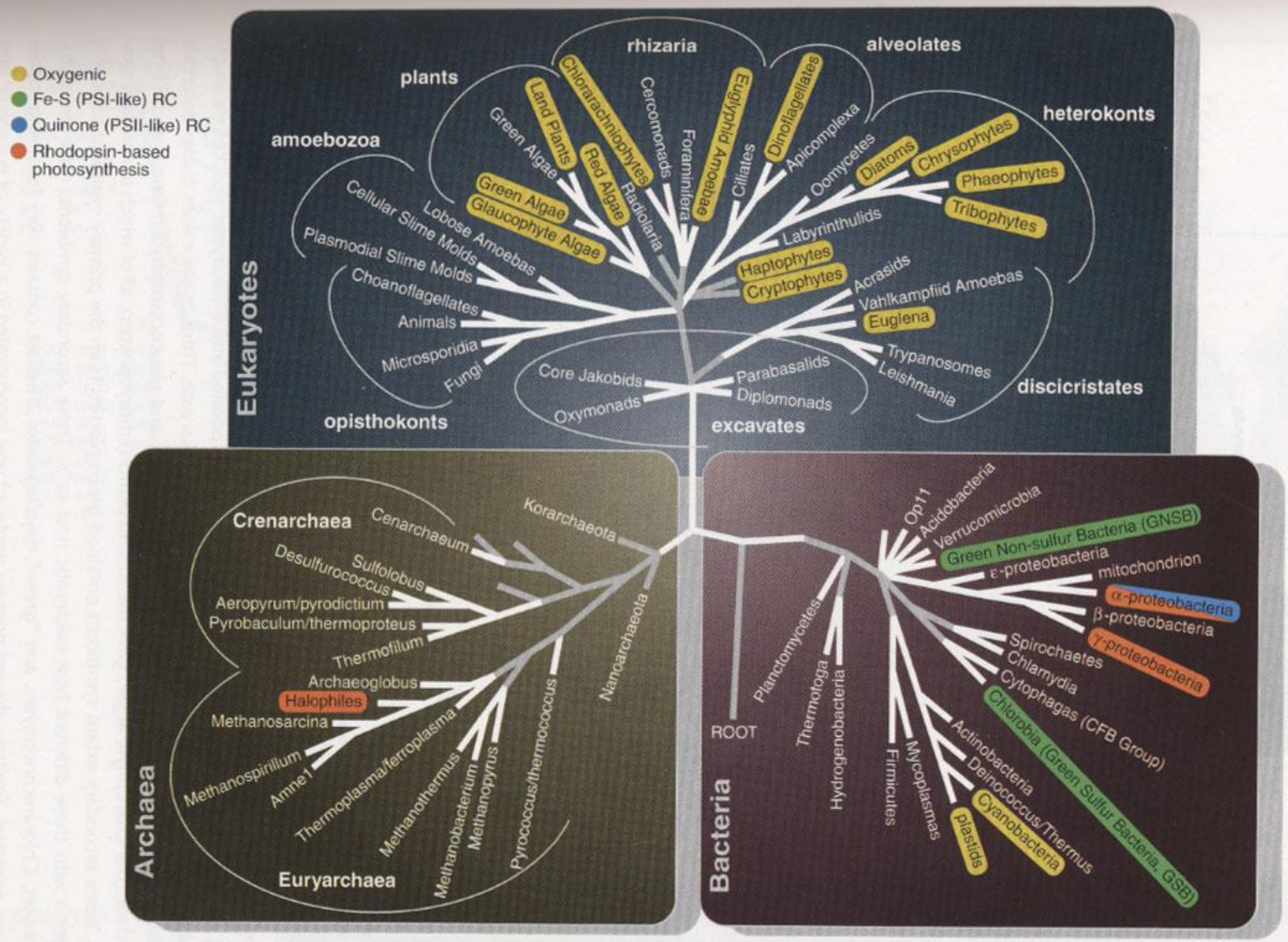
The Mn cluster in PS II



Nature’s insurance policy

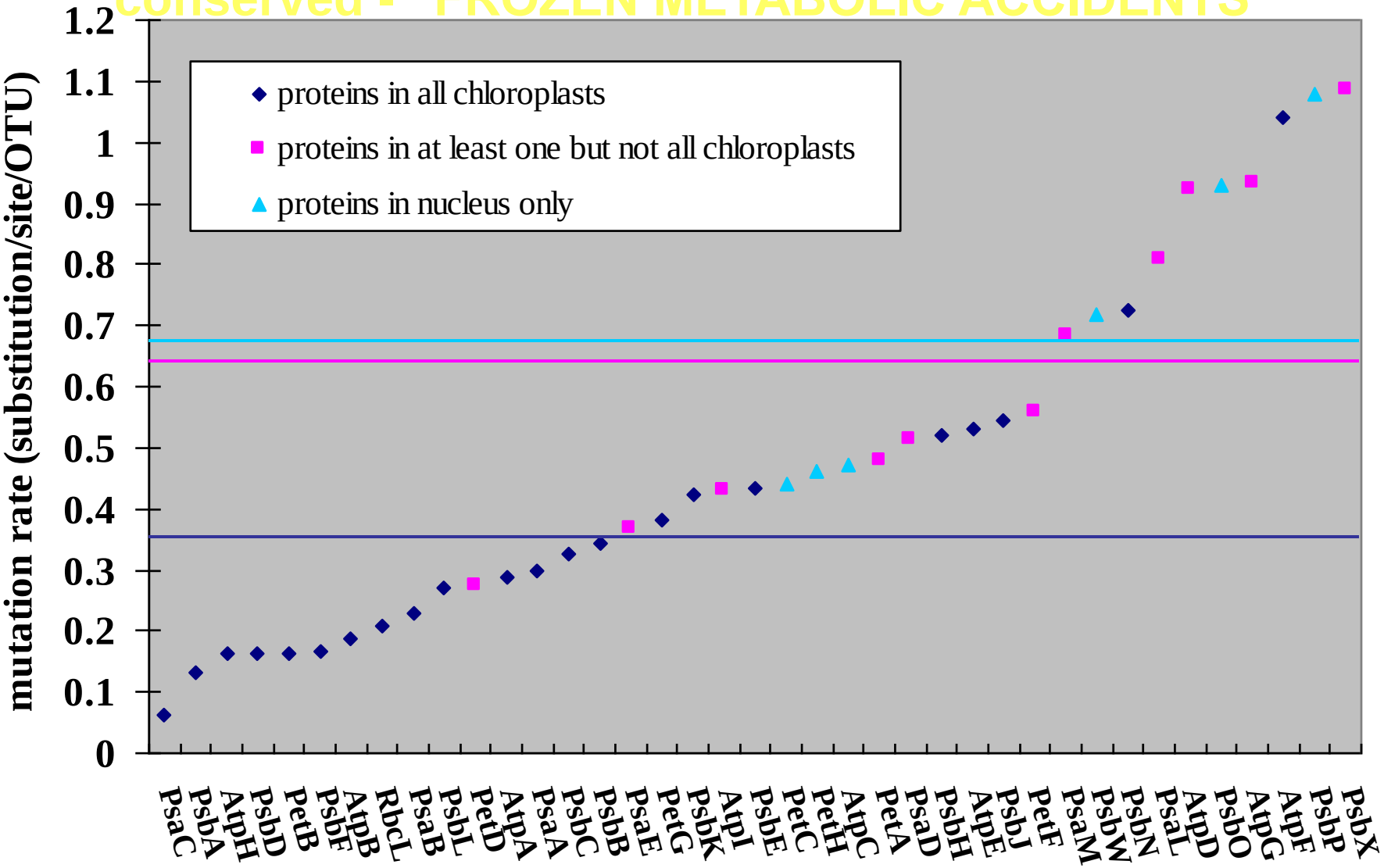
Spread the risk

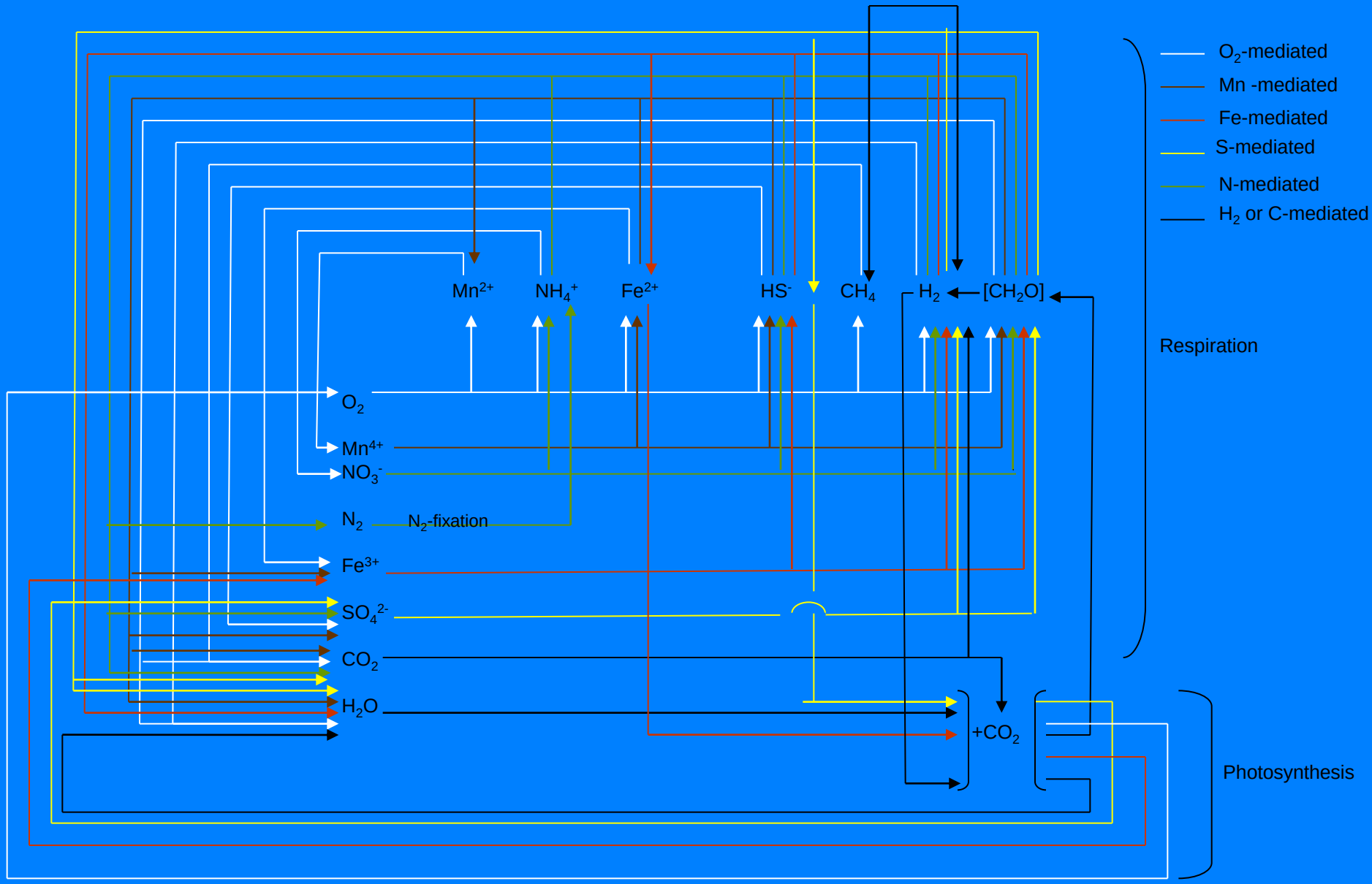

Terrestrial
Aquatic
Organic carbon
ATP
PSII Chla
PSI Chla
e-
H_2O
CO_2
O_2
Prokaryote
Cyanobacteria
Mitochondrion
Nucleus
Eukaryote
Plastid
Primary endosymbiosis
Oxygenic photosynthesis spreads via endosymbiosis
Green plastid
Chla–Chlb
Preference for Fe, Zn, Cu
Green algae
Green algal progenitors of land plants
Glaucophytes
Red plastid
Chla phycobilins
Preference for Mn, Co, Cd
Red algae
Secondary symbioses
Euglenoid host cell
Cercozoan host cell
Alveolate host cell
Alveolate host cell
Prechromist host cell
Prechromist host cell
Prechromist host cell
Land plants
Euglenoids
Chlorarachniophytes
Cryptophytes
Chla–chlc phycobilins
Coccolithophores
Calcareous Haptophytes
Chla–chlc fucoxanthins
Tertiary endosymbiosis
Dinoflagellate host cell
Dinoflagellates
Chla–chlb
Chla–Chlc peridinin
Chla–Chlc fucoxanthins or phycobilins
Grasses
Silica mobilization ?
Diatoms
Heterokonts, siliceous, vacuolated, Chla–Chlc fucoxanthin

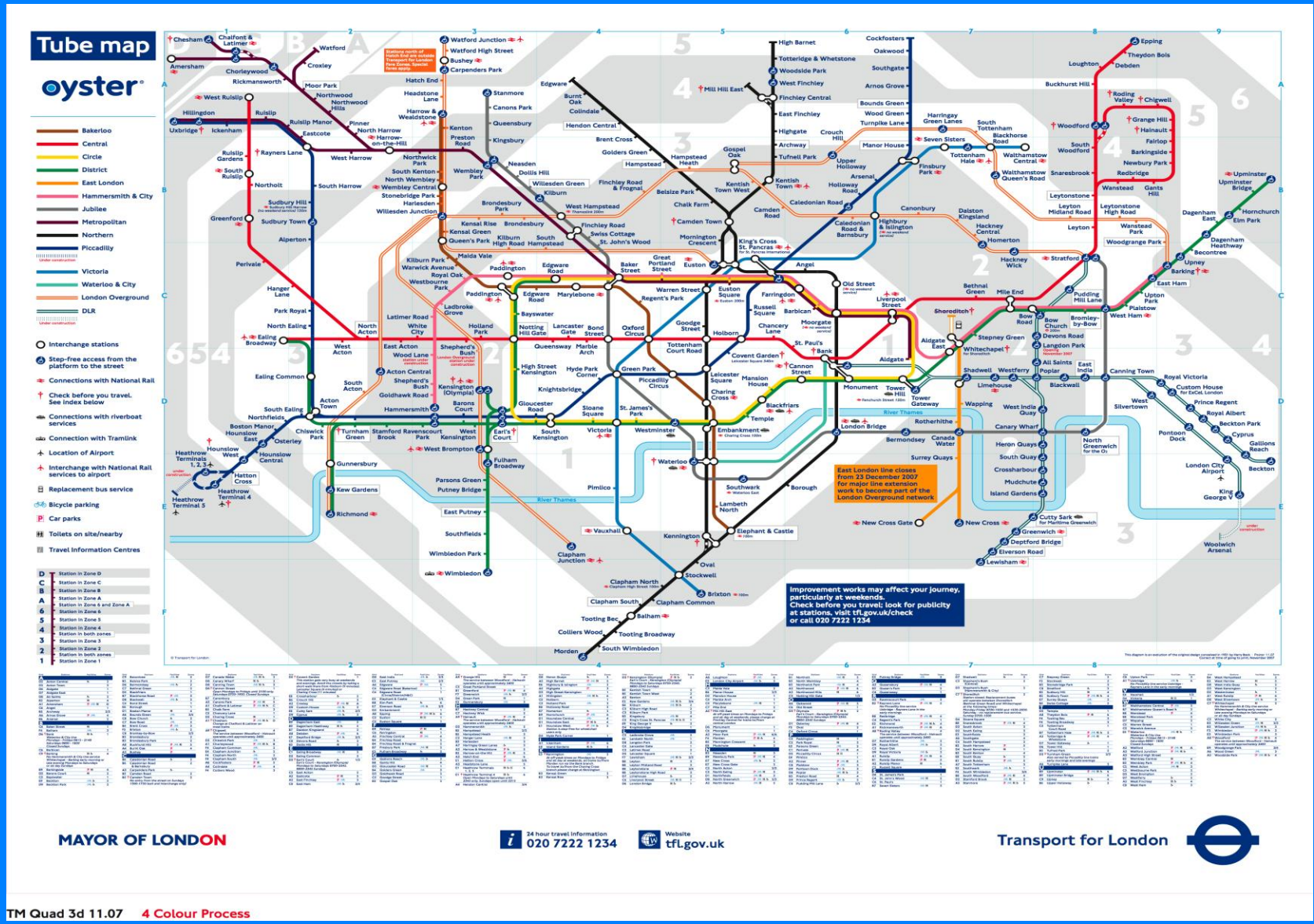


Color Plate 1: A phylogenetic tree of life constructed from ribosomal DNA and other traits showing the evolutionary patterns of major clades of known porkaryotic and eukaryotic taxa and the distribution of photosynthetic metabolic pathways among them. (This tree was modified from a figure kindly provided by Sandie Baldauf.)

PS genes retained in chloroplasts are very highly conserved - “FROZEN METABOLIC ACCIDENTS”




O_2-mediated
Mn -mediated
Fe-mediated
S-mediated
N-mediated
H_2 or C-mediated
Respiration
Photosynthesis
Mn^{2+}
NH_4^+
Fe^{2+}
HS^-
CH_4
H_2
$[CH_2O]$
O_2
Mn^{4+}
NO_3^-
N_2
N_2-fixation
Fe^{3+}
SO_4^{2-}
CO_2
H_2O
$+CO_2$



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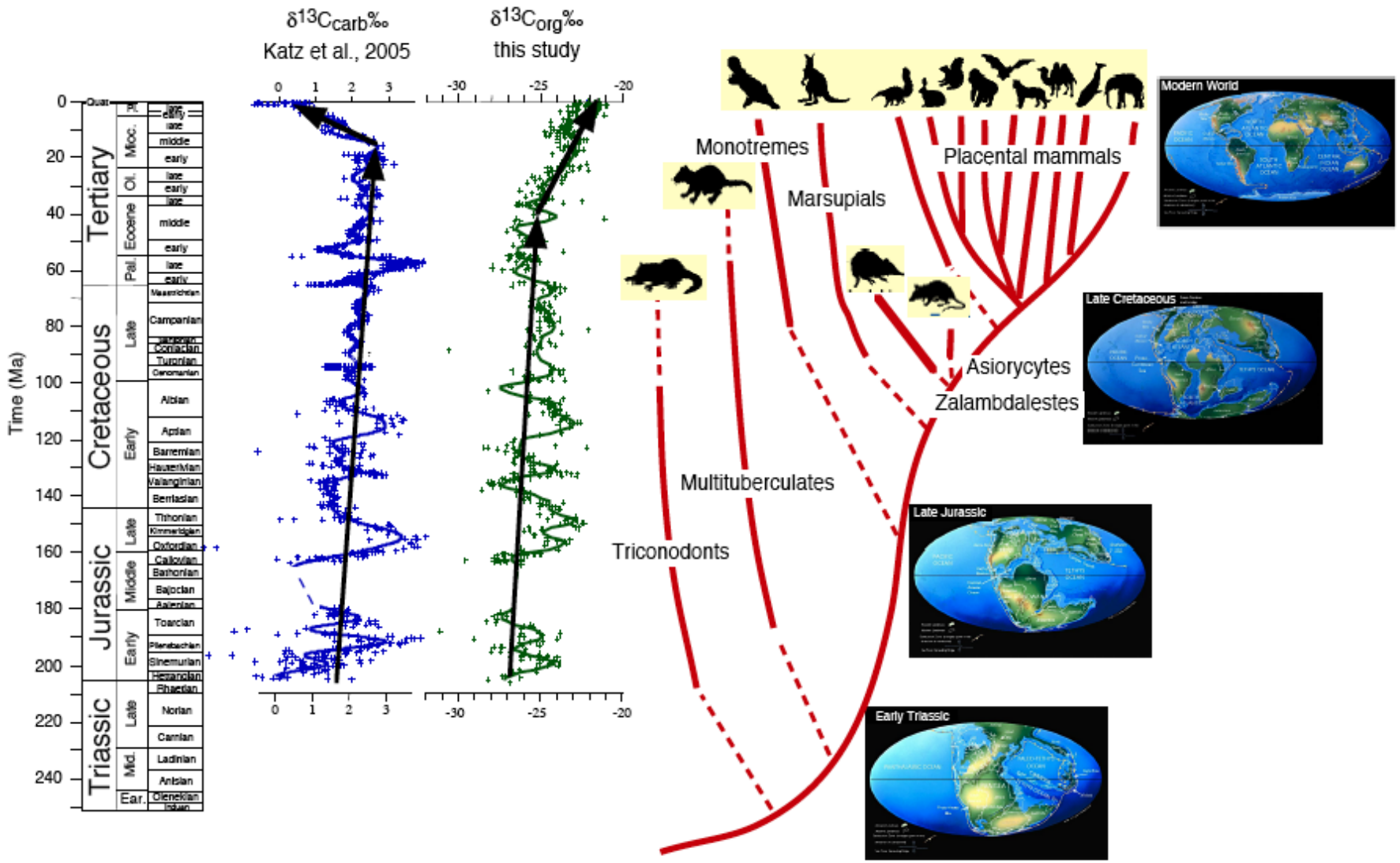
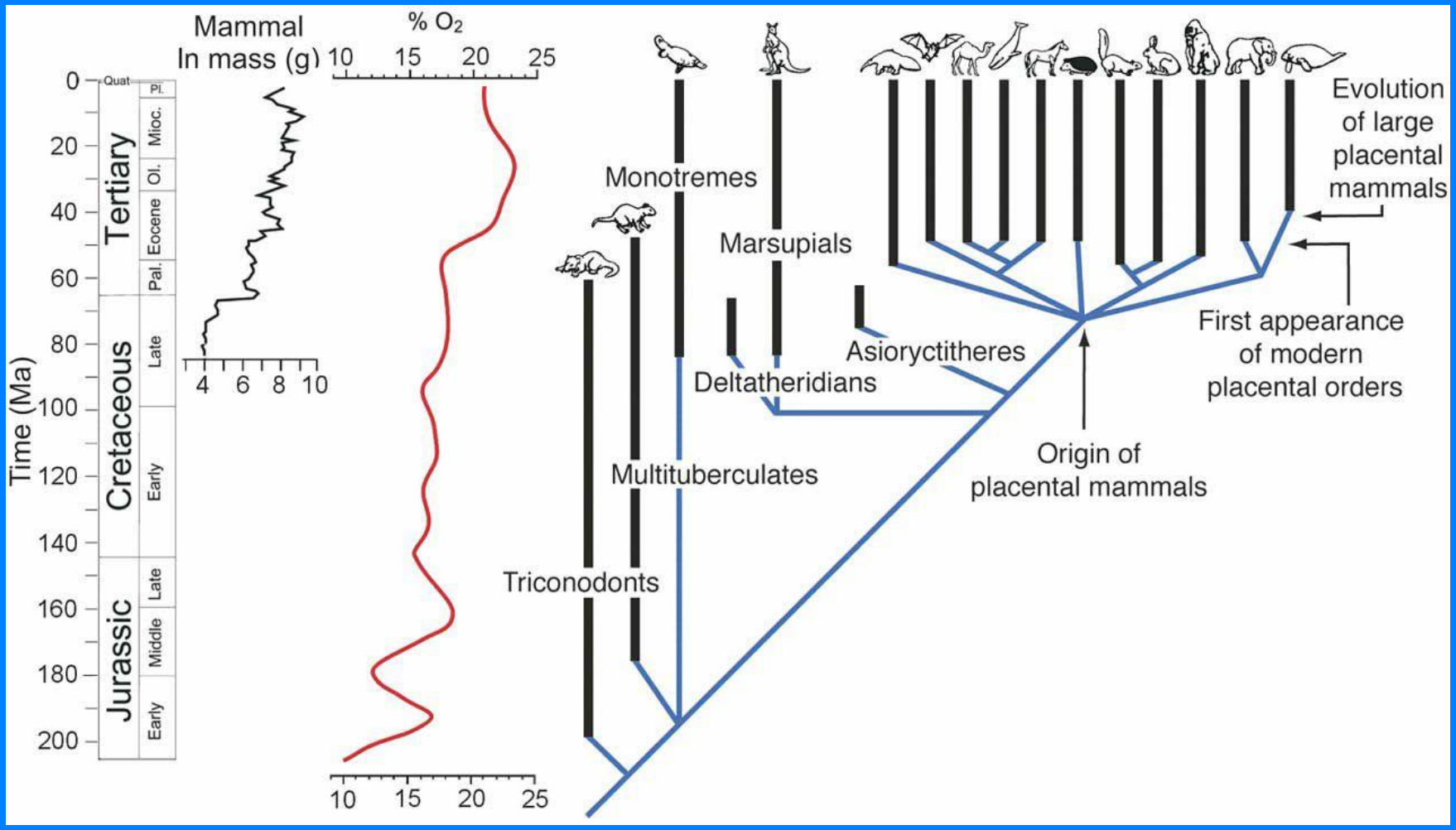

δ13Ccarb‰
Katz et al., 2005
δ13Corg‰
this study
Time (Ma)
Tertiary
Cretaceous
Jurassic
Triassic
Monotremes
Marsupials
Placental mammals
Asiorycytes
Zalambdalestes
Multituberculates
Triconodonts
Modern World
Late Cretaceous
Late Jurassic
Early Triassic


Mammal
ln mass (g)
% O_2
Time (Ma)
Quat
Pl.
Tertiary
Mioc.
Ol.
Eocene
Pal.
Cretaceous
Late
Early
Jurassic
Late
Middle
Early
Monotremes
Marsupials
Deltatheridians
Asioryctitheres
Multituberculates
Triconodonts
Origin of placental mammals
First appearance of modern placental orders
Evolution of large placental mammals

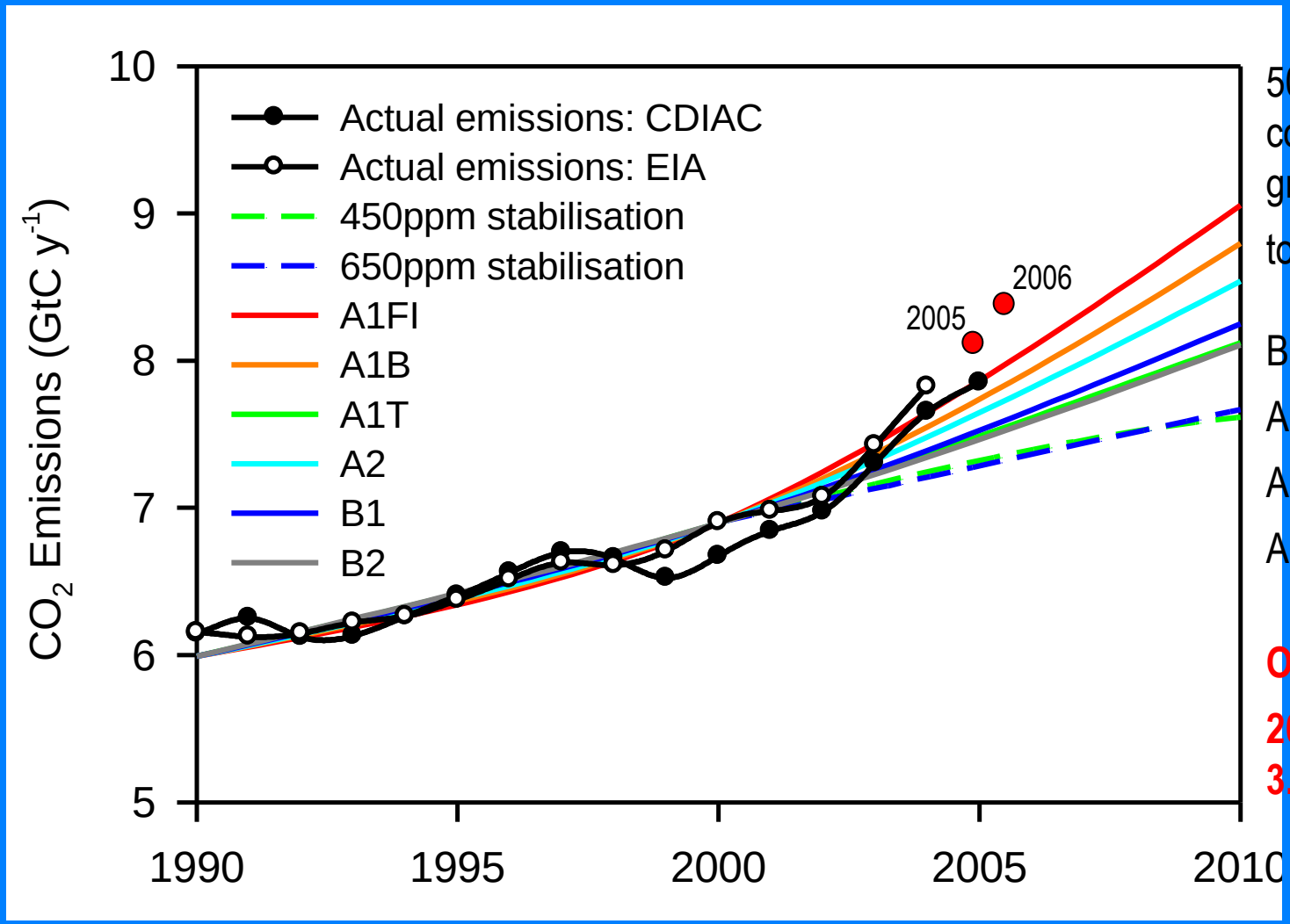
Earth is “hard wired” by mircobial metabolism

Effectively, the metabolism of Earth was created over 2 billion years ago - and hasn’t changed very much.

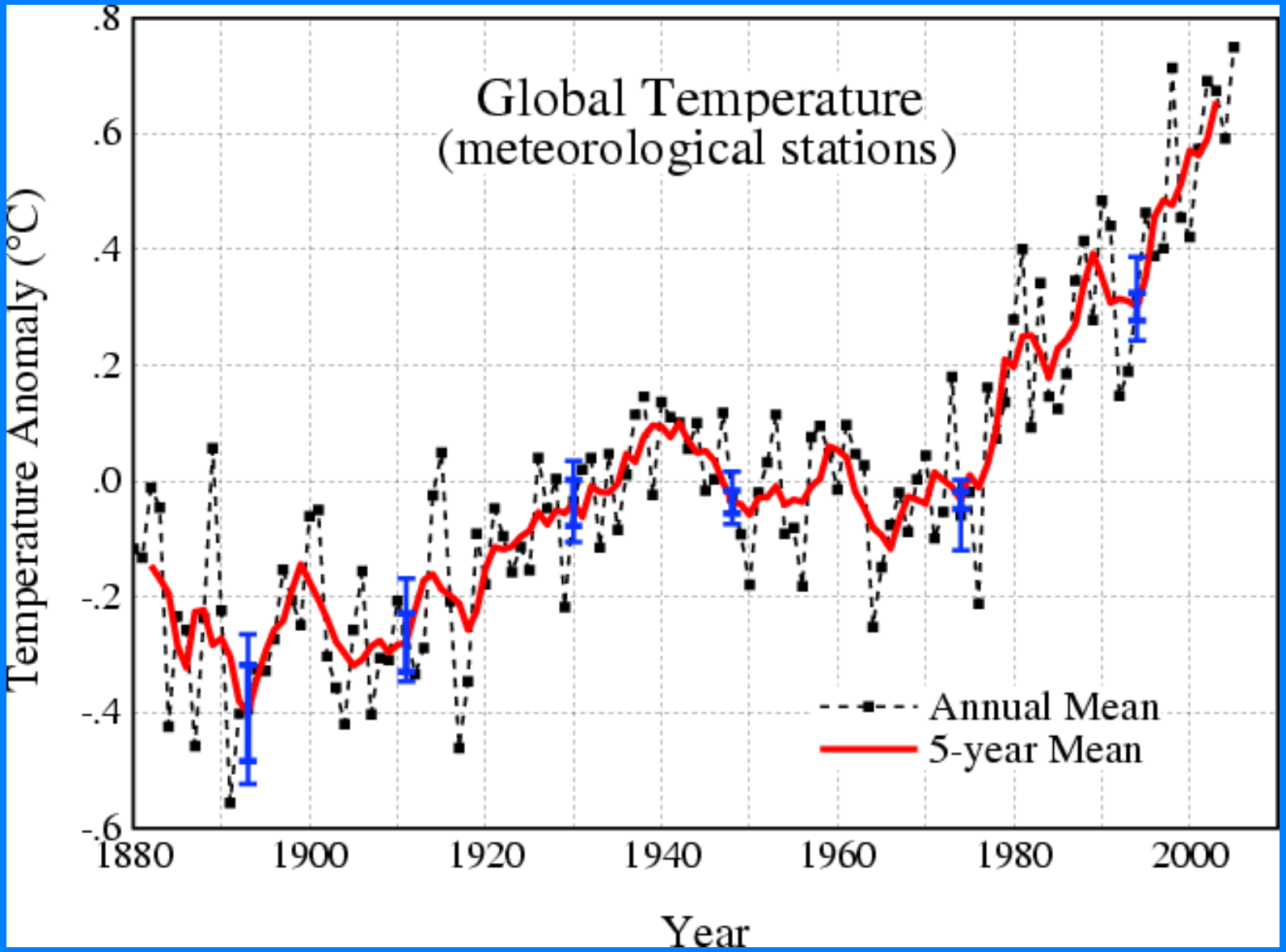
Humans are effectively, fragile, inefficient E. coli that have learned how to plunder the planet

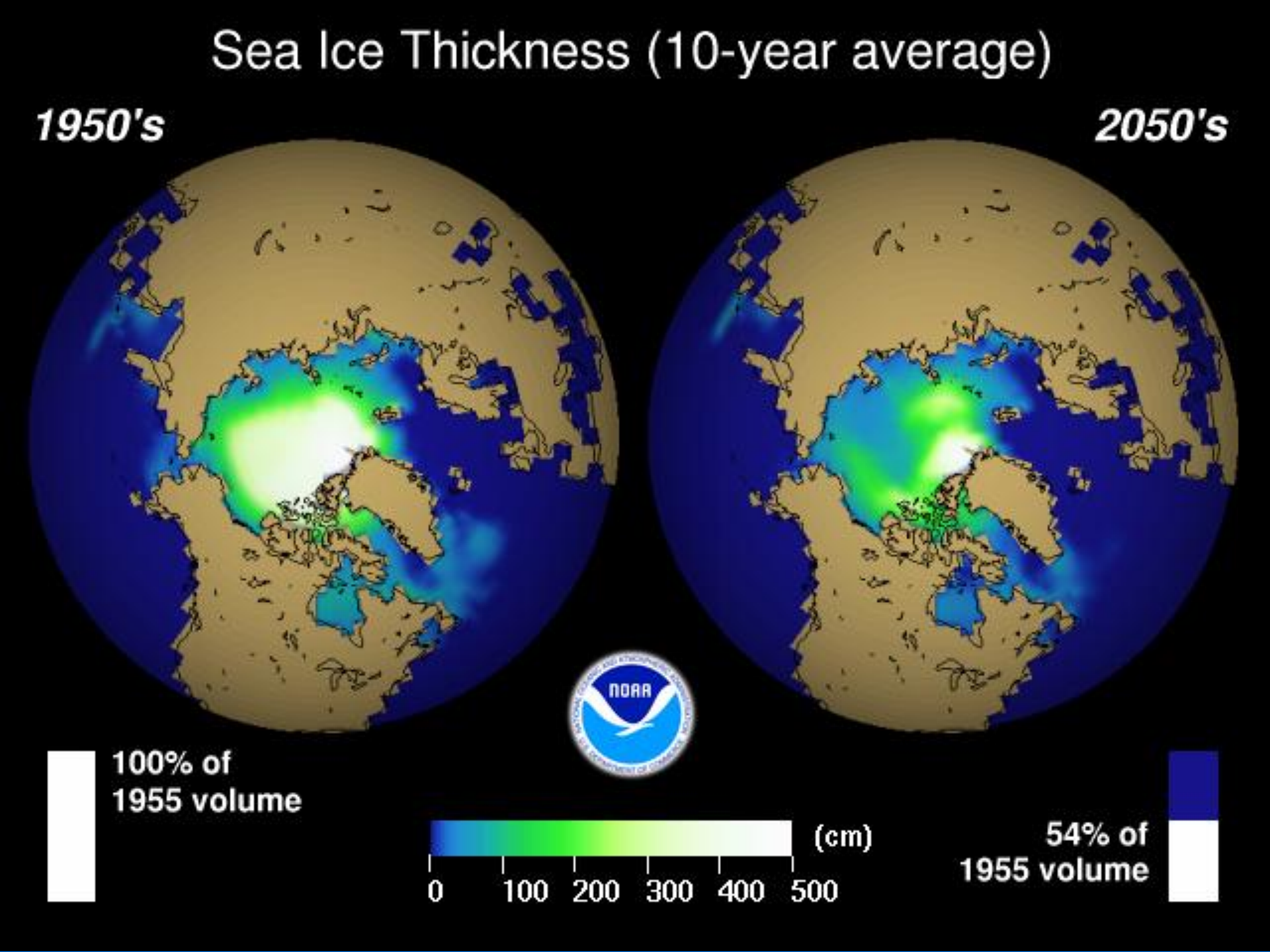
Source: Falkowski 2002 Scientific American

Trajectory of Global Fossil Fuel Emissions

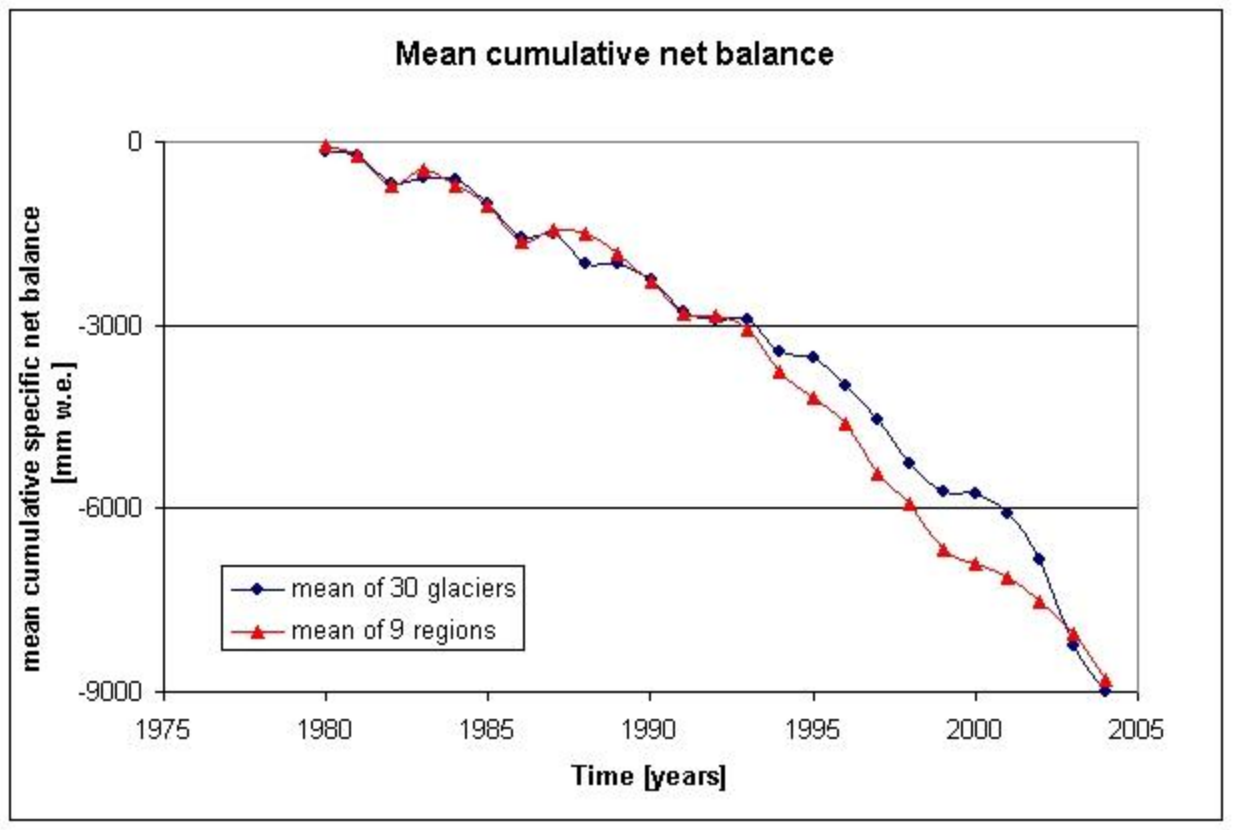


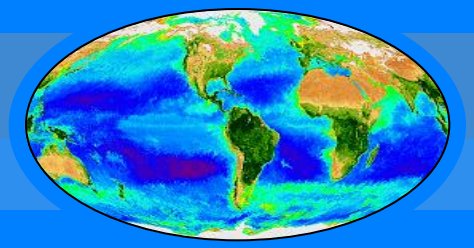
Raupach et al. 2007, PNAS


Global Temperature
(meteorological stations)
Temperature Anomaly (°C)
.8
.6
.4
.2
.0
-.2
-.4
-.6
1880
1900
1920
1940
1960
1980
2000
Year
Annual Mean
5-year Mean


Sea Ice Thickness (10-year average)
1950's
2050's
NOAA
100% of
1955 volume
(cm)
0
100
200
300
400
500
54% of
1955 volume

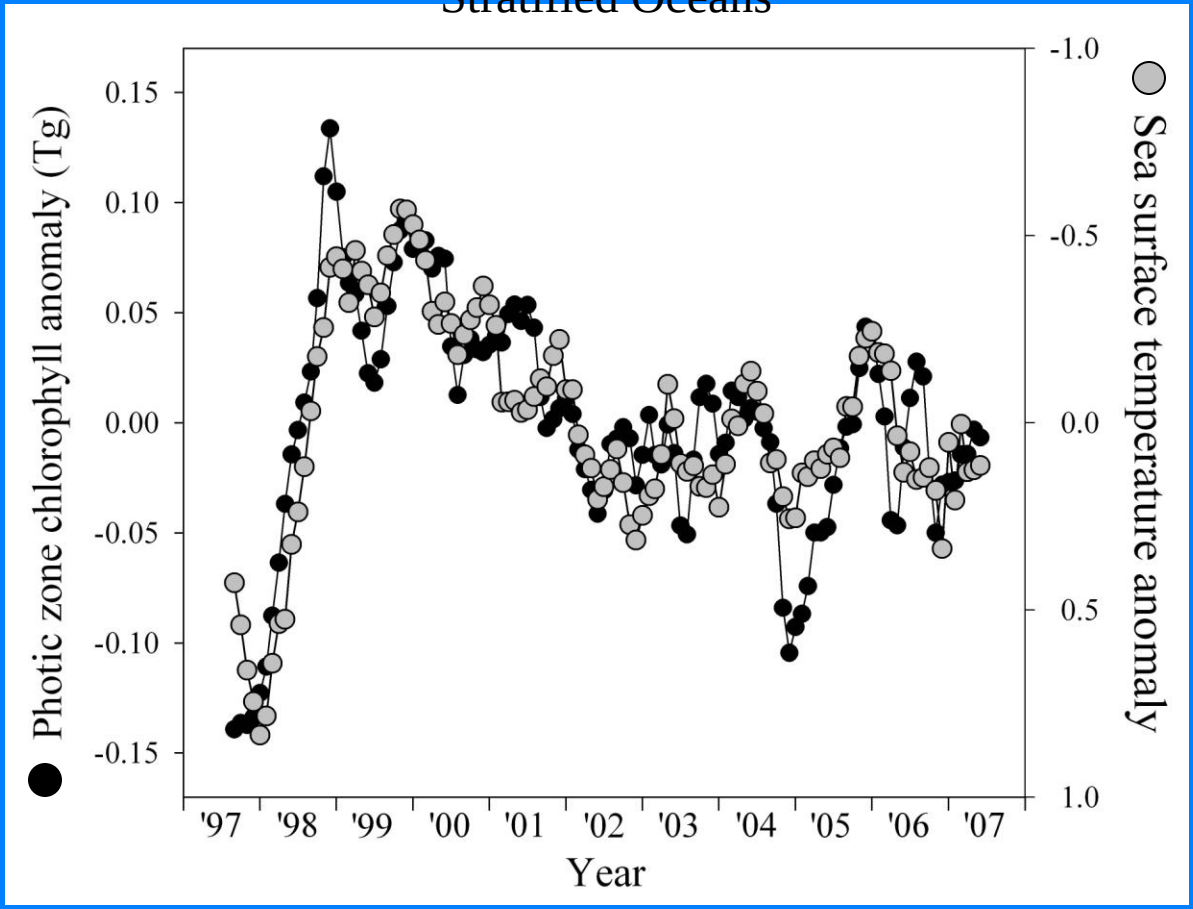
Changes in Glacier Mass





Phytoplankton & Climate

Stratified Oceans



CONCLUSIONS

- THE EARTH IS FUNDAMENTALLY A “BOTTOM UP” SYSTEM IN WHICH MICROBES HAVE ADAPTED OVER (LITERALLY) BILLIONS OF YEARS TO MAINTIAN A QUASI-STEADY STATE
- HUMANS, THROUGH EFFICIENT RESOURCE PLUNDER, WILL MODIFY EARTH’S ATMOSPHERE AND CLIMATE - BUT MICROBES WILL EASILY SURVIVE.
- ANIMALS (INCLUDING HUMANS) AND SOME PLANTS ARE EXTREMELY VULNERABLE TO HUMAN ACTIVITIES - AND MANY SPECIES PROBABLYWILL GO EXTINCT IN THIS CENTURY.