XIX Всемирный фестиваль молодёжи и студентов

# The 21st Century Singularity and Mathematical Modeling of the Planetary History

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National Research University Higher School of Economics & Oriental Institute of the Russian Academy of Sciences

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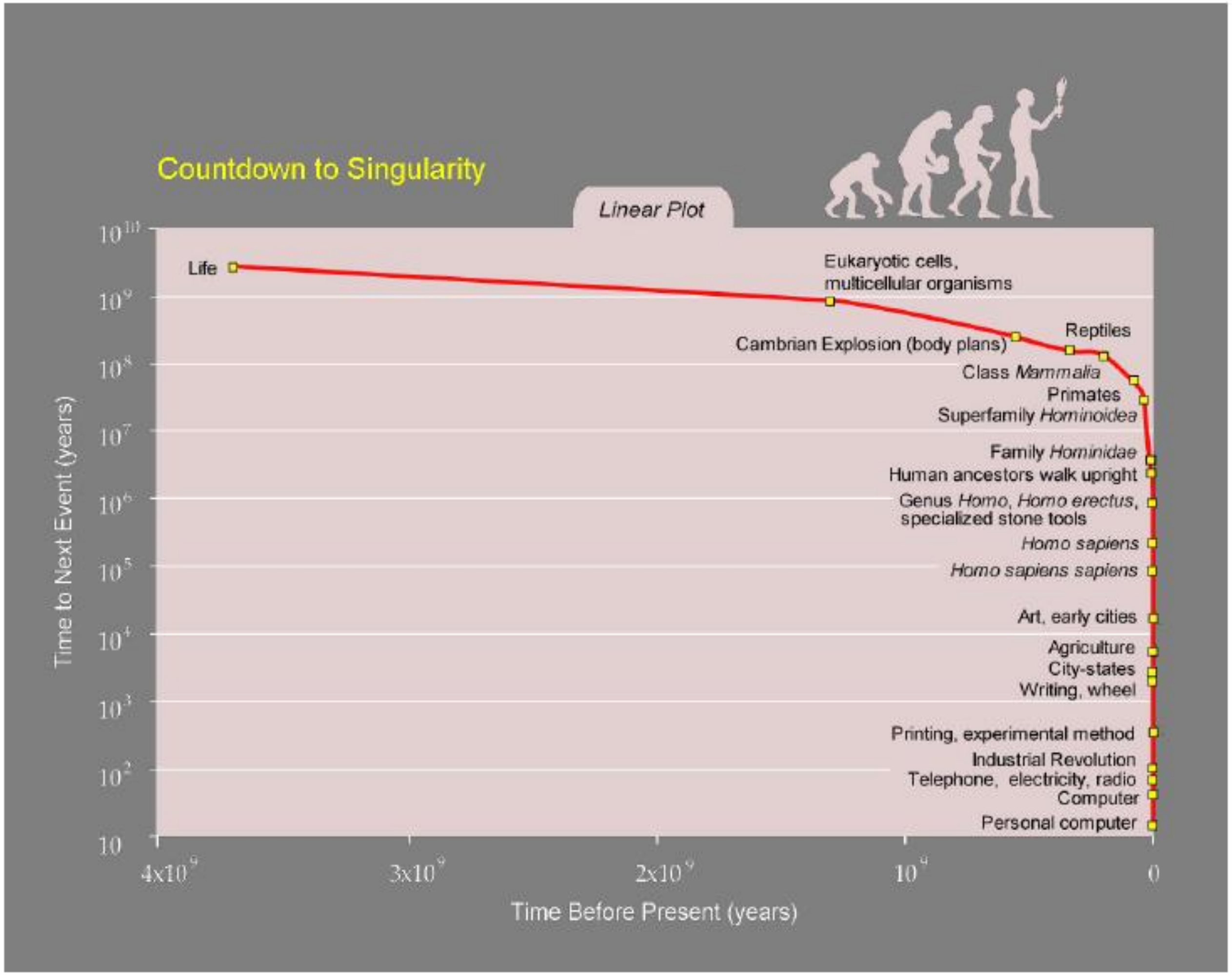
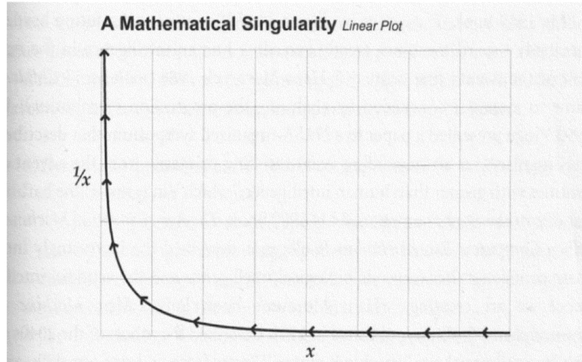
WHEN HUMANS TRANSCEND BIOLOGY

# THE SINGULARITY IS NEAR

## RAY KURZWEIL

AUTHOR OF *THE AGE OF SPIRITUAL MACHINES*


Countdown to Singularity
Linear Plot
Life
Eukaryotic cells, multicellular organisms
Cambrian Explosion (body plans)
Reptiles
Class Mammalia
Primates
Superfamily Hominoidea
Family Hominidae
Human ancestors walk upright
Genus Homo, Homo erectus, specialized stone tools
Homo sapiens
Homo sapiens sapiens
Art, early cities
Agriculture
City-states
Writing, wheel
Printing, experimental method
Industrial Revolution
Telephone, electricity, radio
Computer
Personal computer
Time to Next Event (years)
Time Before Present (years)

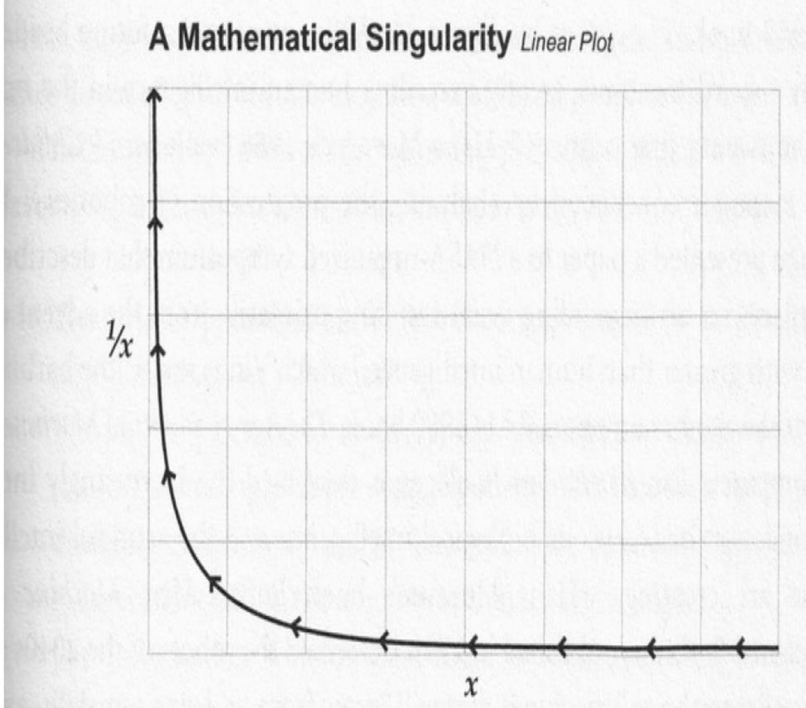



*A mathematical singularity:* As *x* approaches zero (from right to left), 1/*x* (or *y*) approaches infinity.

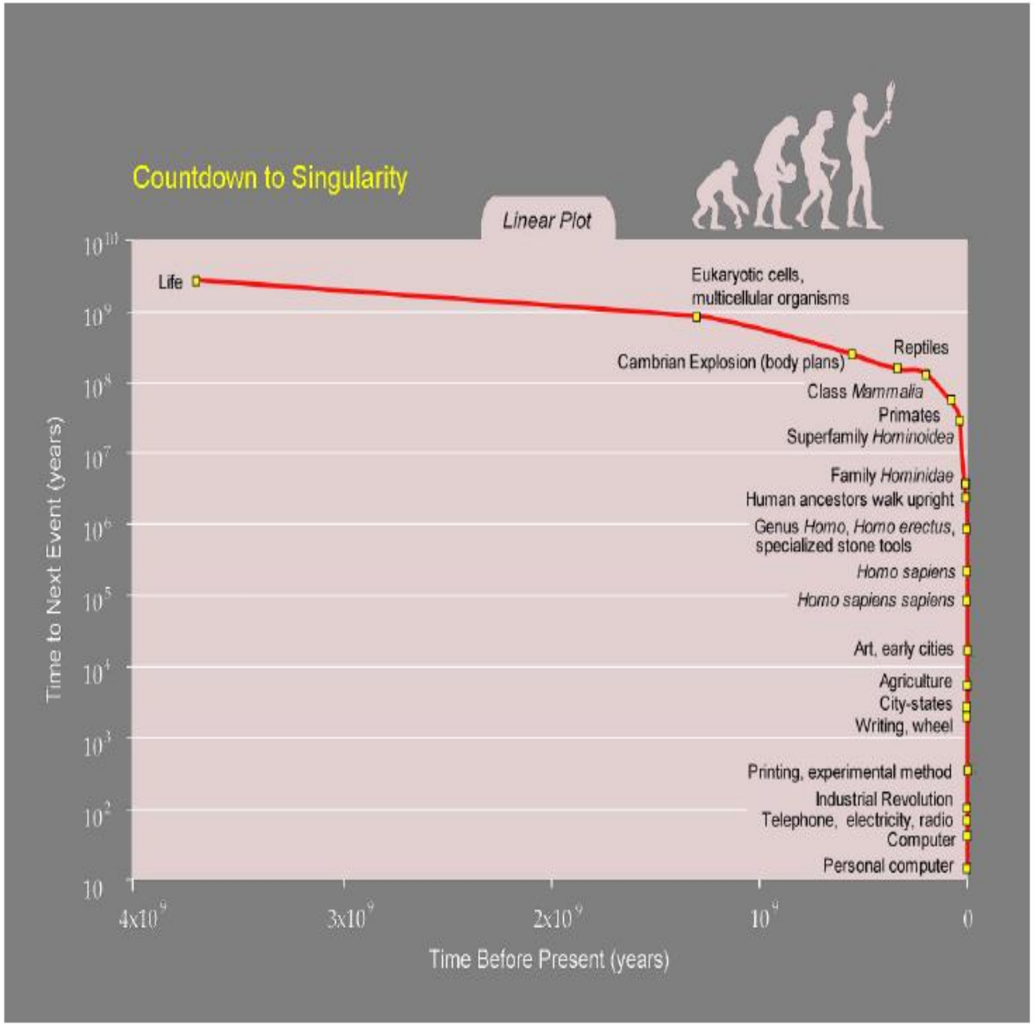
To put the concept of Singularity into further perspective, let's explore the history of the word itself. "Singularity" is an English word meaning a unique event with, well, singular implications. The word was adopted by mathematicians to denote a value that transcends any finite limitation, such as the explosion of magnitude that results when dividing a constant by a number that gets closer and closer to zero. Consider, for example, the simple function $y = 1/x$. As the value of $x$ approaches zero, the value of the function ($y$) explodes to larger and larger values.

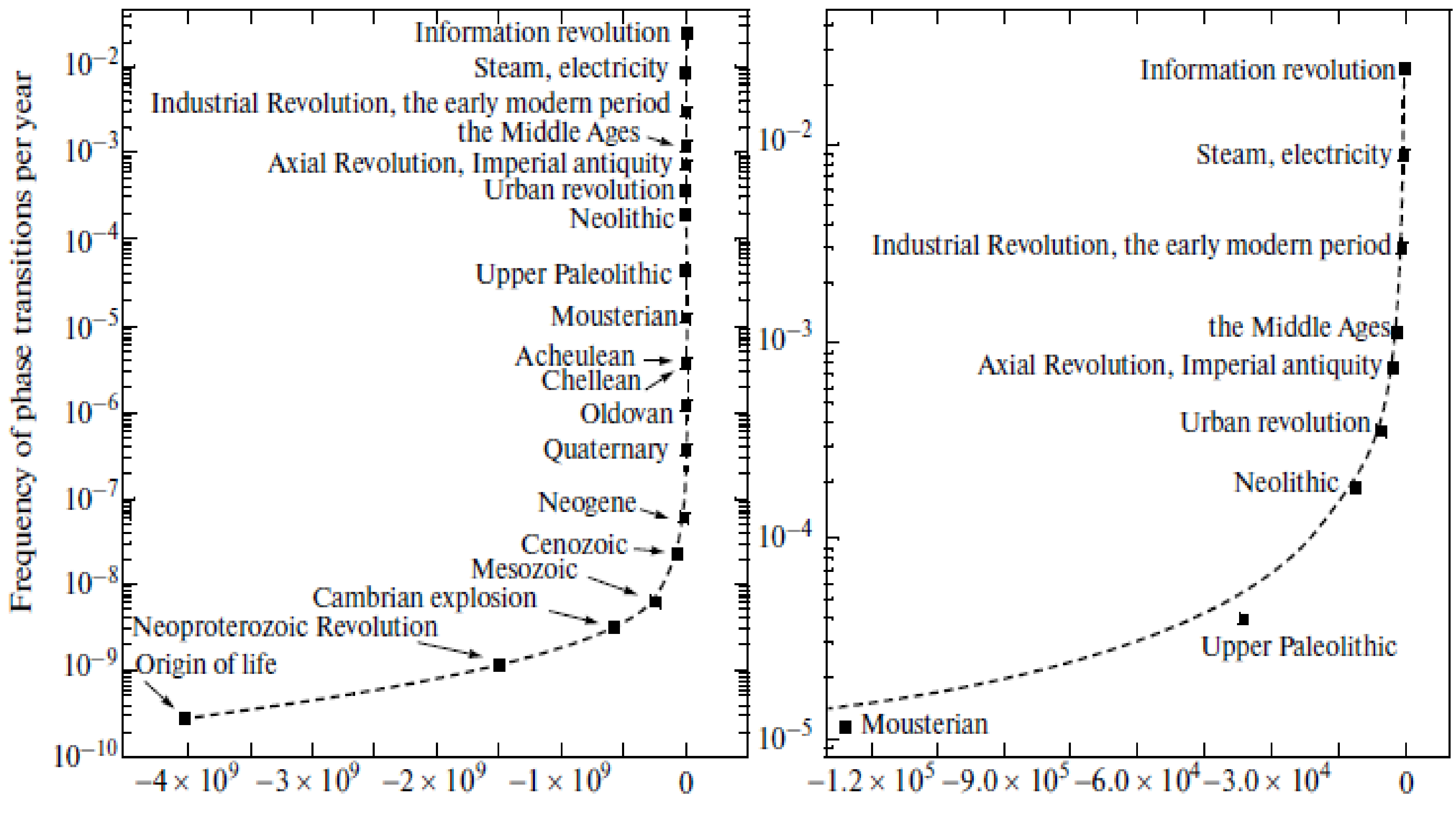
Such a mathematical function never actually achieves an infinite value, since dividing by zero is mathematically "undefined" (impossible to calculate). But the value of $y$ exceeds any possible finite limit (approaches infinity) as the divisor $x$ approaches zero.

The next field to adopt the word was astrophysics. If a massive star undergoes a supernova explosion, its remnant eventually collapses to the point of apparently zero volume and infinite density, and a "singularity" is created at its center. Because light was thought to be unable to escape the star after it reached this infinite density,[16] it was called a




*A mathematical singularity:* As *x* approaches zero (from right to left) $1/x$ (or *y*) approaches infinity.





Frequency of phase transitions per year
Information revolution
Steam, electricity
Industrial Revolution, the early modern period
the Middle Ages
Axial Revolution, Imperial antiquity
Urban revolution
Neolithic
Upper Paleolithic
Mousterian
Acheulean
Chellean
Oldovan
Quaternary
Neogene
Cenozoic
Mesozoic
Cambrian explosion
Neoproterozoic Revolution
Origin of life
$10^{-2}$ $10^{-3}$ $10^{-4}$ $10^{-5}$ $10^{-6}$ $10^{-7}$ $10^{-8}$ $10^{-9}$ $10^{-10}$
$-4 \times 10^9$ $-3 \times 10^9$ $-2 \times 10^9$ $-1 \times 10^9$ 0
Information revolution
Steam, electricity
Industrial Revolution, the early modern period
the Middle Ages
Axial Revolution, Imperial antiquity
Urban revolution
Neolithic
Upper Paleolithic
Mousterian
$10^{-2}$ $10^{-3}$ $10^{-4}$ $10^{-5}$
$-1.2 \times 10^5$ $-9.0 \times 10^5$ $-6.0 \times 10^4$ $-3.0 \times 10^4$ 0

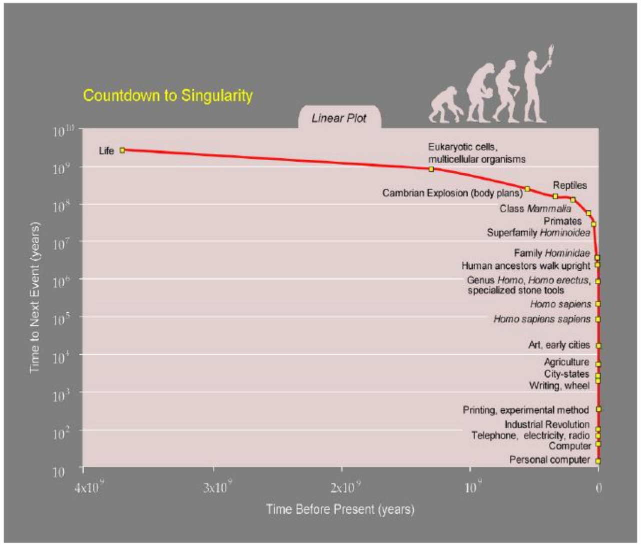
$$t_n = t^* - T / \alpha^n$$

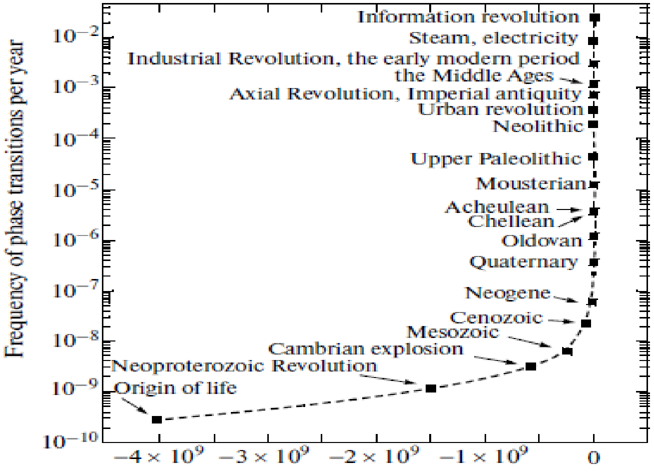
$$\lg(t^* - t_n) = \lg T - n \lg \alpha$$

**Сингулярность Панова – Дьяконова**

alpha = 2,67

t* = 2004 г. н.э.


Countdown to Singularity
Linear Plot
Time to Next Event (years)
Life
Eukaryotic cells, multicellular organisms
Reptiles
Cambrian Explosion (body plans)
Class Mammalia
Primates
Superfamily Hominoidea
Family Hominidae
Human ancestors walk upright
Genus Homo, Homo erectus, specialized stone tools
Homo sapiens
Homo sapiens sapiens
Art, early cities
Agriculture
City-states
Writing, wheel
Printing, experimental method
Industrial Revolution
Telephone, electricity, radio
Computer
Personal computer
Time Before Present (years)


Frequency of phase transitions per year
Information revolution
Steam, electricity
Industrial Revolution, the early modern period
the Middle Ages
Axial Revolution, Imperial antiquity
Urban revolution
Neolithic
Upper Paleolithic
Mousterian
Acheulean
Chellean
Oldovan
Quaternary
Neogene
Cenozoic
Mesozoic
Cambrian explosion
Neoproterozoic Revolution
Origin of life

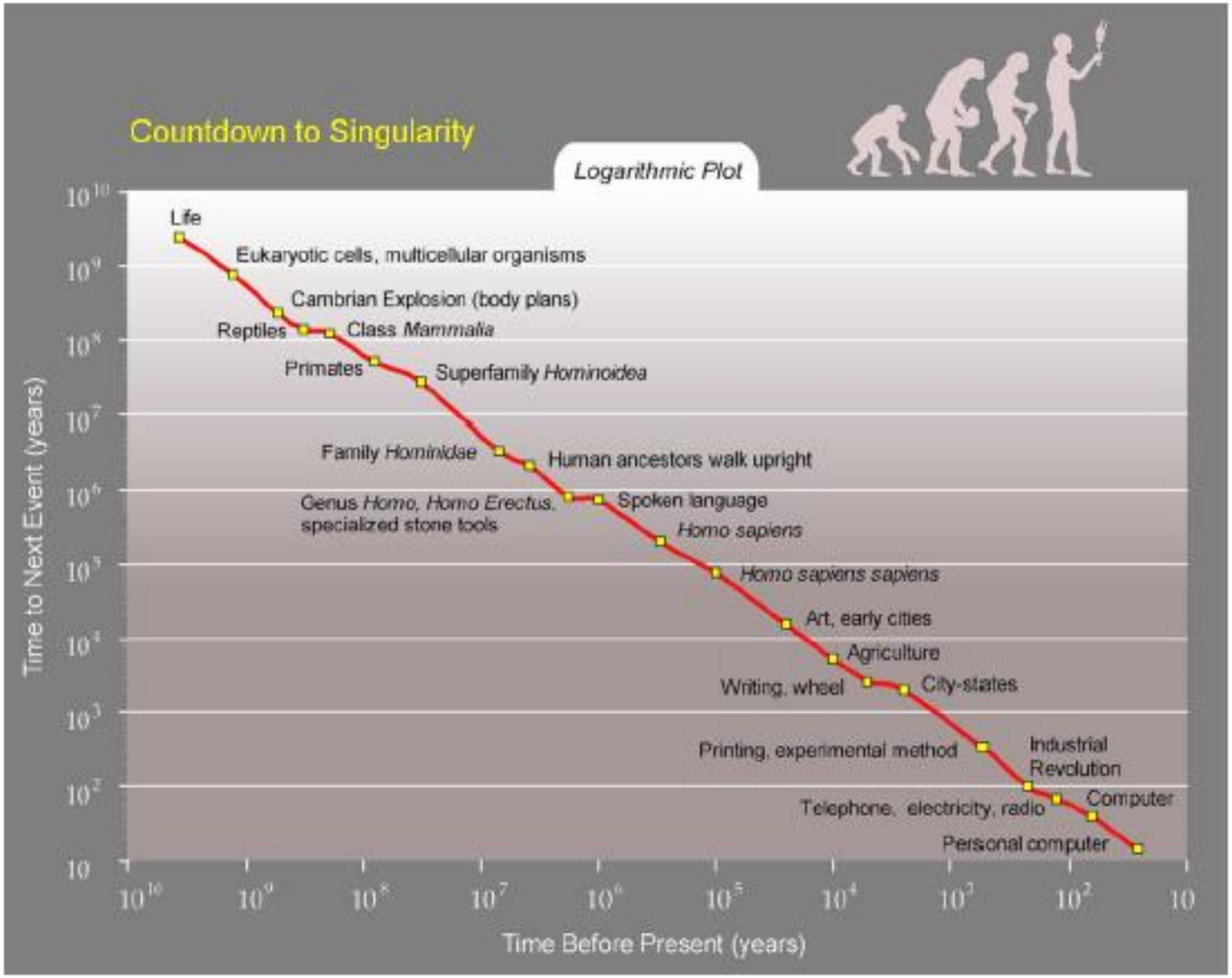
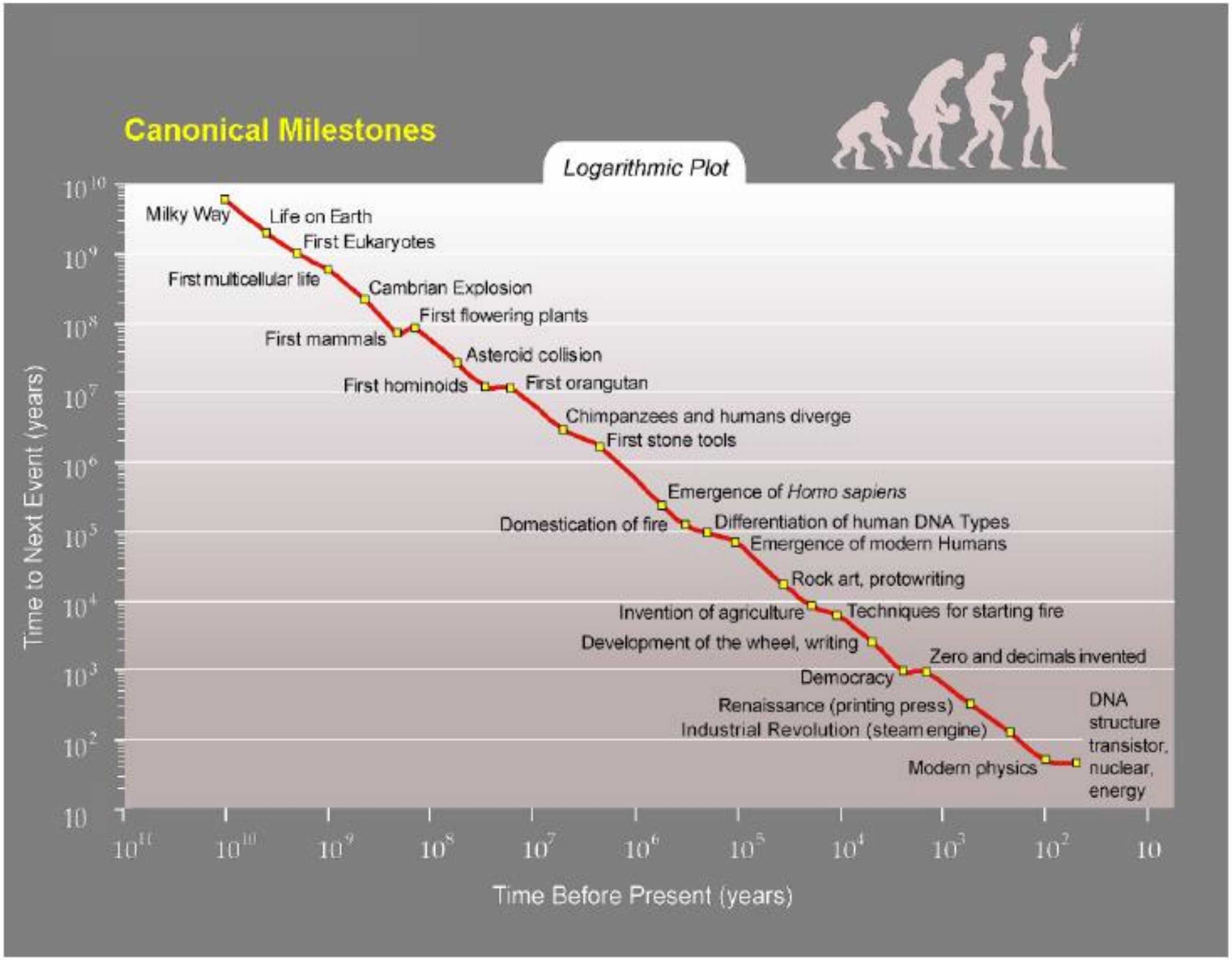
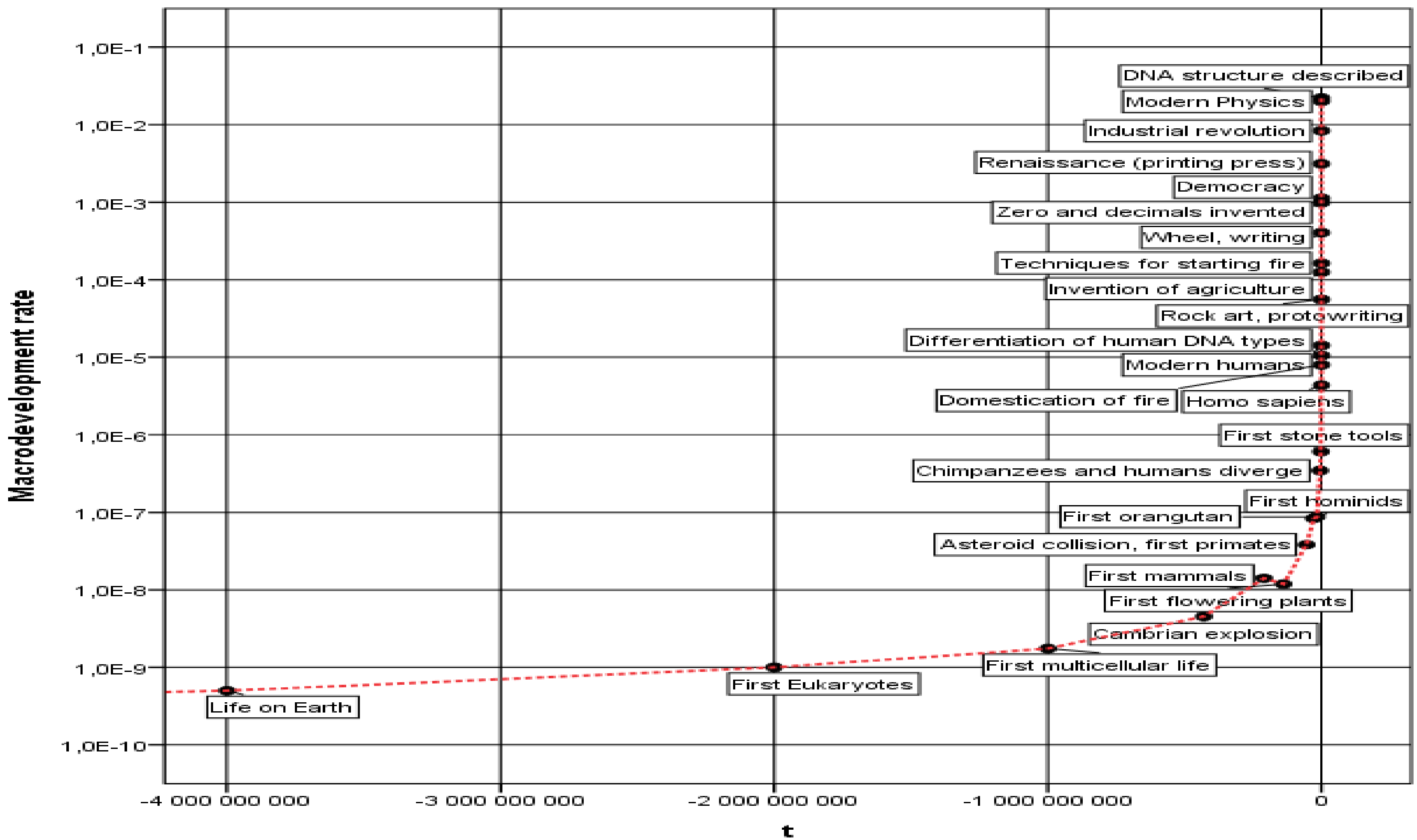

Countdown to Singularity
Logarithmic Plot
Time to Next Event (years)
Time Before Present (years)
Life
Eukaryotic cells, multicellular organisms
Cambrian Explosion (body plans)
Reptiles
Class *Mammalia*
Primates
Superfamily *Hominoidea*
Family *Hominidae*
Human ancestors walk upright
Genus *Homo*, *Homo Erectus*, specialized stone tools
Spoken language
*Homo sapiens*
*Homo sapiens sapiens*
Art, early cities
Agriculture
Writing, wheel
City-states
Printing, experimental method
Industrial Revolution
Telephone, electricity, radio
Computer
Personal computer

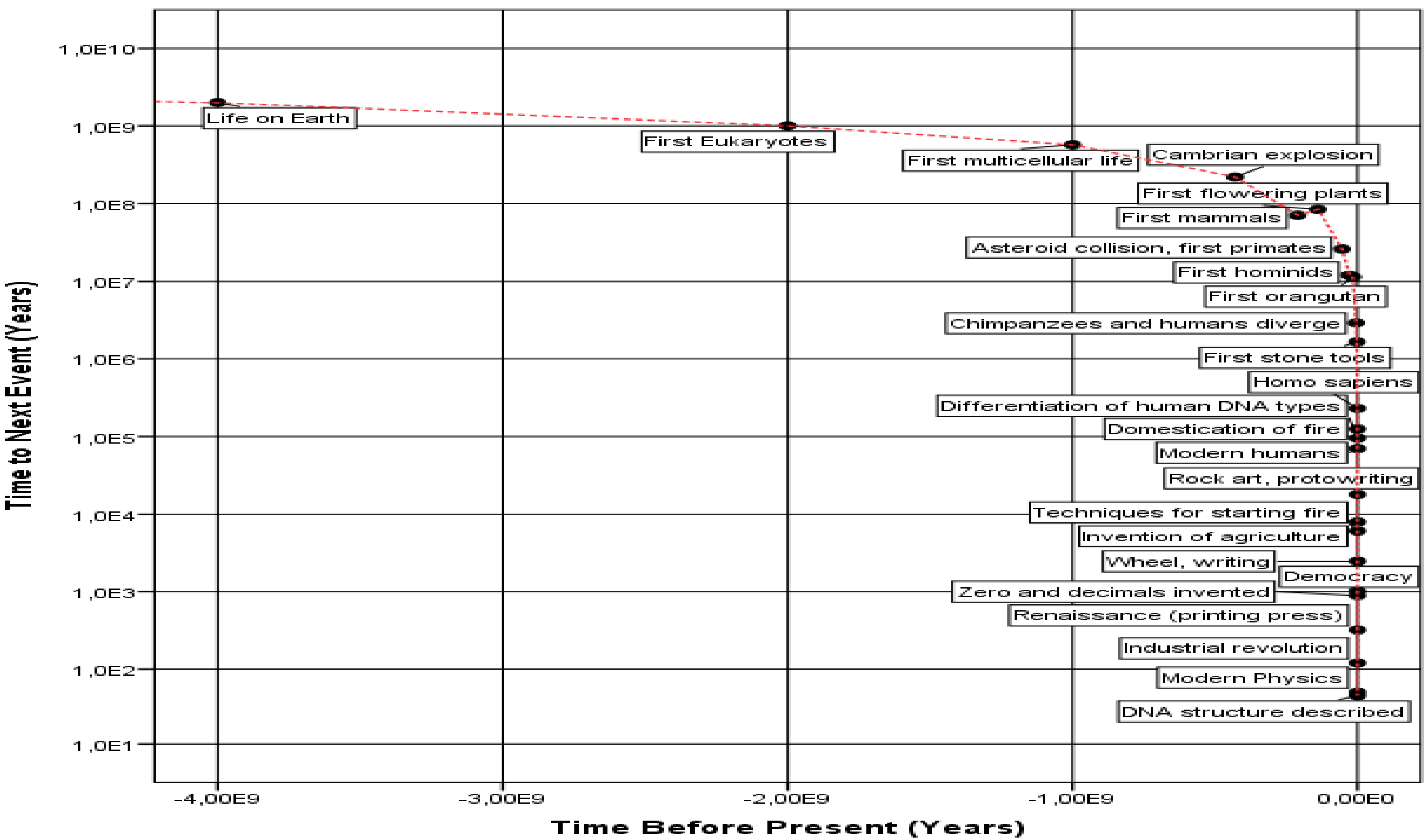
Fig. 5



Canonical Milestones
Logarithmic Plot
Milky Way
Life on Earth
First Eukaryotes
First multicellular life
Cambrian Explosion
First flowering plants
First mammals
Asteroid collision
First hominoids
First orangutan
Chimpanzees and humans diverge
First stone tools
Emergence of *Homo sapiens*
Domestication of fire
Differentiation of human DNA Types
Emergence of modern Humans
Rock art, protowriting
Invention of agriculture
Techniques for starting fire
Development of the wheel, writing
Zero and decimals invented
Democracy
Renaissance (printing press)
Industrial Revolution (steam engine)
DNA structure transistor, nuclear, energy
Modern physics
Time to Next Event (years)
Time Before Present (years)
$10^{10}$ $10^{9}$ $10^{8}$ $10^{7}$ $10^{6}$ $10^{5}$ $10^{4}$ $10^{3}$ $10^{2}$ 10
$10^{11}$ $10^{10}$ $10^{9}$ $10^{8}$ $10^{7}$ $10^{6}$ $10^{5}$ $10^{4}$ $10^{3}$ $10^{2}$ 10


Fig. 6


Macrodevelopment rate
1,0E-1
1,0E-2
1,0E-3
1,0E-4
1,0E-5
1,0E-6
1,0E-7
1,0E-8
1,0E-9
1,0E-10
DNA structure described
Modern Physics
Industrial revolution
Renaissance (printing press)
Democracy
Zero and decimals invented
Wheel, writing
Techniques for starting fire
Invention of agriculture
Rock art, protowriting
Differentiation of human DNA types
Modern humans
Domestication of fire
Homo sapiens
First stone tools
Chimpanzees and humans diverge
First hominids
First orangutan
Asteroid collision, first primates
First mammals
First flowering plants
Cambrian explosion
First multicellular life
First Eukaryotes
Life on Earth
-4 000 000 000
-3 000 000 000
-2 000 000 000
-1 000 000 000
0
t



Time to Next Event (Years)
1,0E10
1,0E9
1,0E8
1,0E7
1,0E6
1,0E5
1,0E4
1,0E3
1,0E2
1,0E1
Life on Earth
First Eukaryotes
First multicellular life
Cambrian explosion
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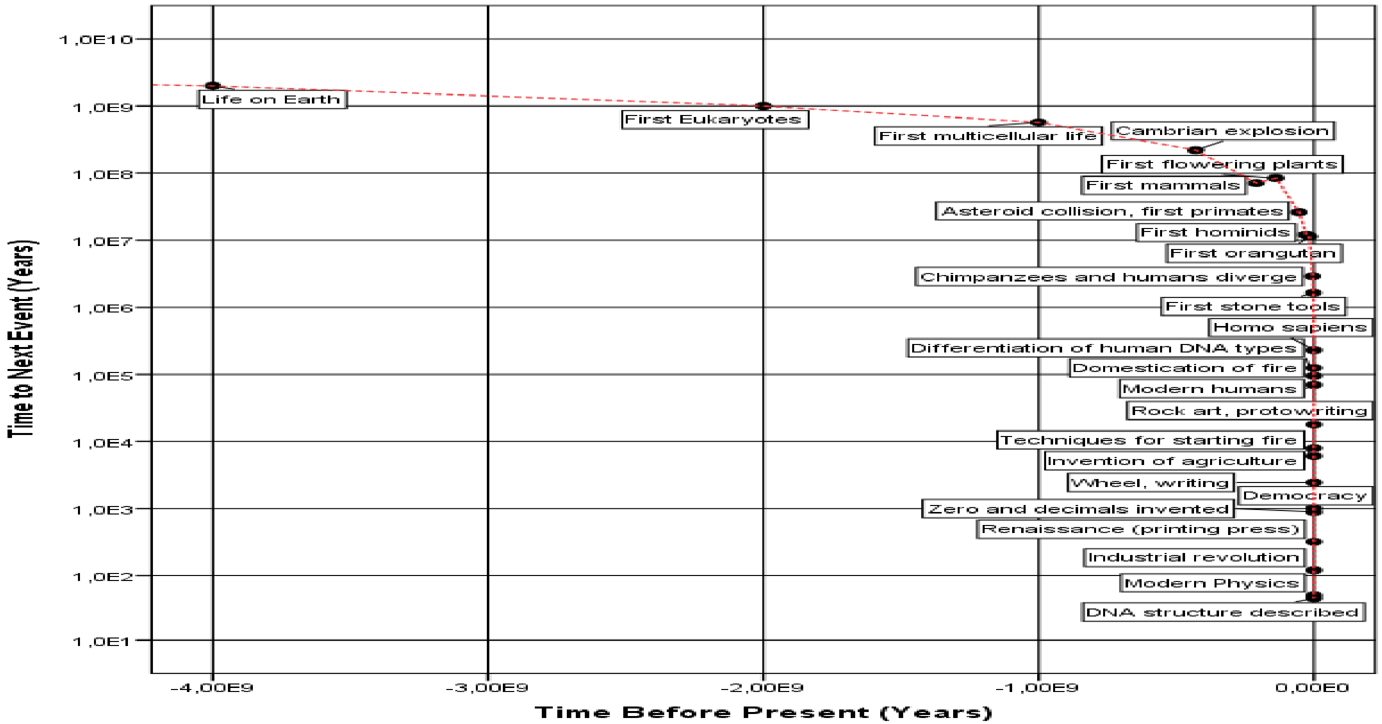
First mammals
Asteroid collision, first primates
First hominids
First orangutan
Chimpanzees and humans diverge
First stone tools
Homo sapiens
Differentiation of human DNA types
Domestication of fire
Modern humans
Rock art, protowriting
Techniques for starting fire
Invention of agriculture
Wheel, writing
Democracy
Zero and decimals invented
Renaissance (printing press)
Industrial revolution
Modern Physics
DNA structure described
-4,00E9
-3,00E9
-2,00E9
-1,00E9
0,00E0
Time Before Present (Years)


Time to Next Event (Years)
1,0E10
1,0E9
1,0E8
1,0E7
1,0E6
1,0E5
1,0E4
1,0E3
1,0E2
1,0E1
Life on Earth
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Asteroid collision, first primates
First hominids
First orangutan
Chimpanzees and humans diverge
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Homo sapiens
Differentiation of human DNA types
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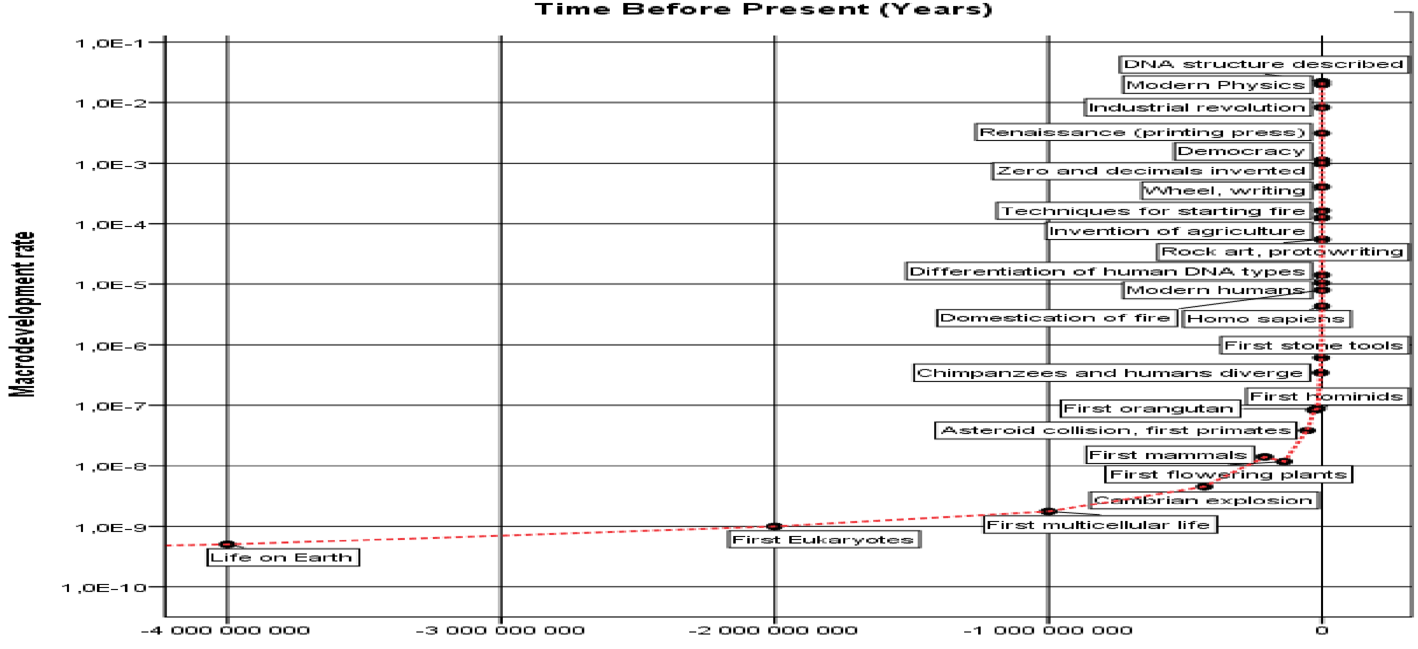
Modern humans
Rock art, protowriting
Techniques for starting fire
Invention of agriculture
Wheel, writing
Democracy
Zero and decimals invented
Renaissance (printing press)
Industrial revolution
Modern Physics
DNA structure described
-4,00E9
-3,00E9
-2,00E9
-1,00E9
0,00E0
Time Before Present (Years)


Macrodevelopment rate
1,0E-1
1,0E-2
1,0E-3
1,0E-4
1,0E-5
1,0E-6
1,0E-7
1,0E-8
1,0E-9
1,0E-10
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Democracy
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Wheel, writing
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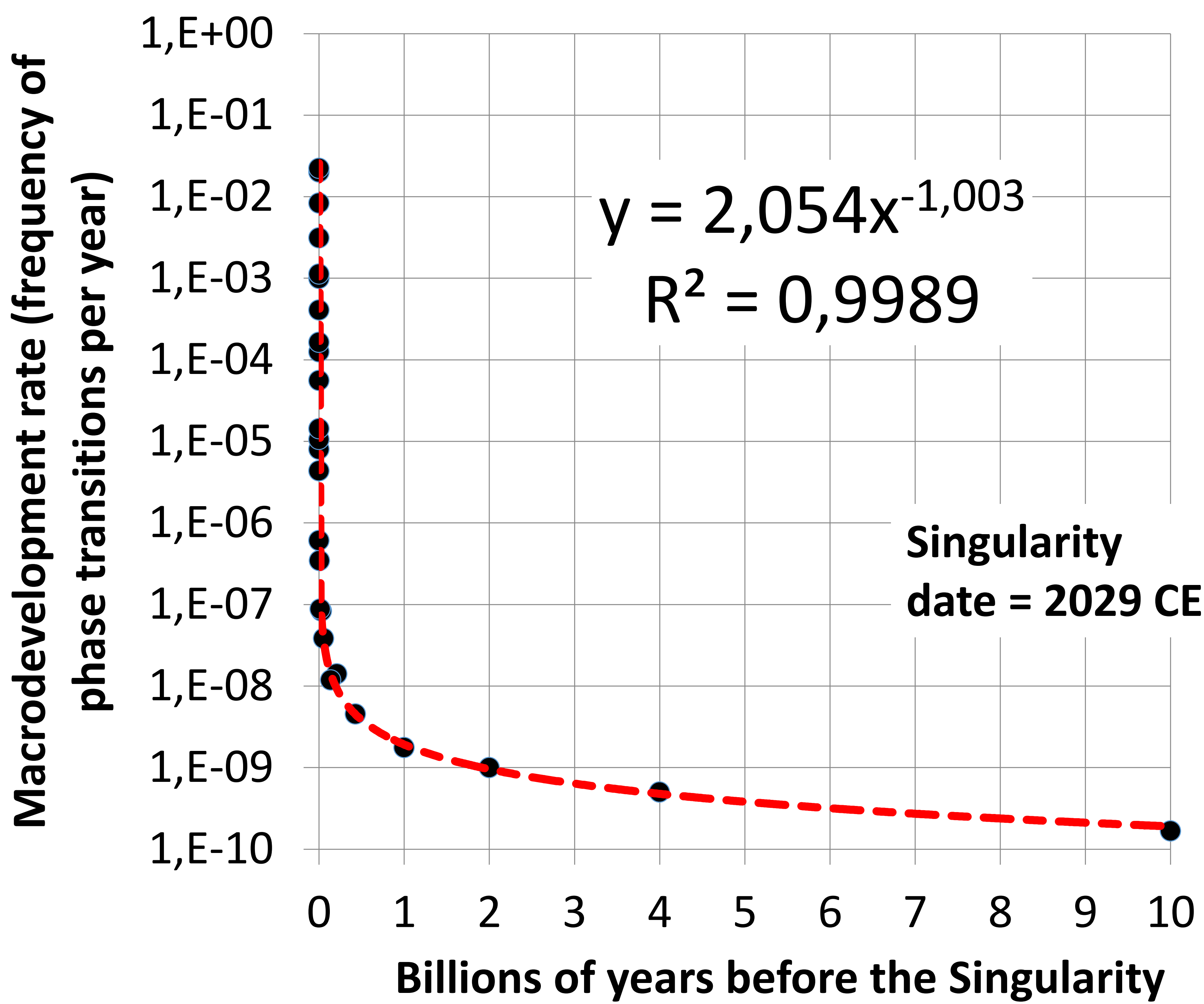
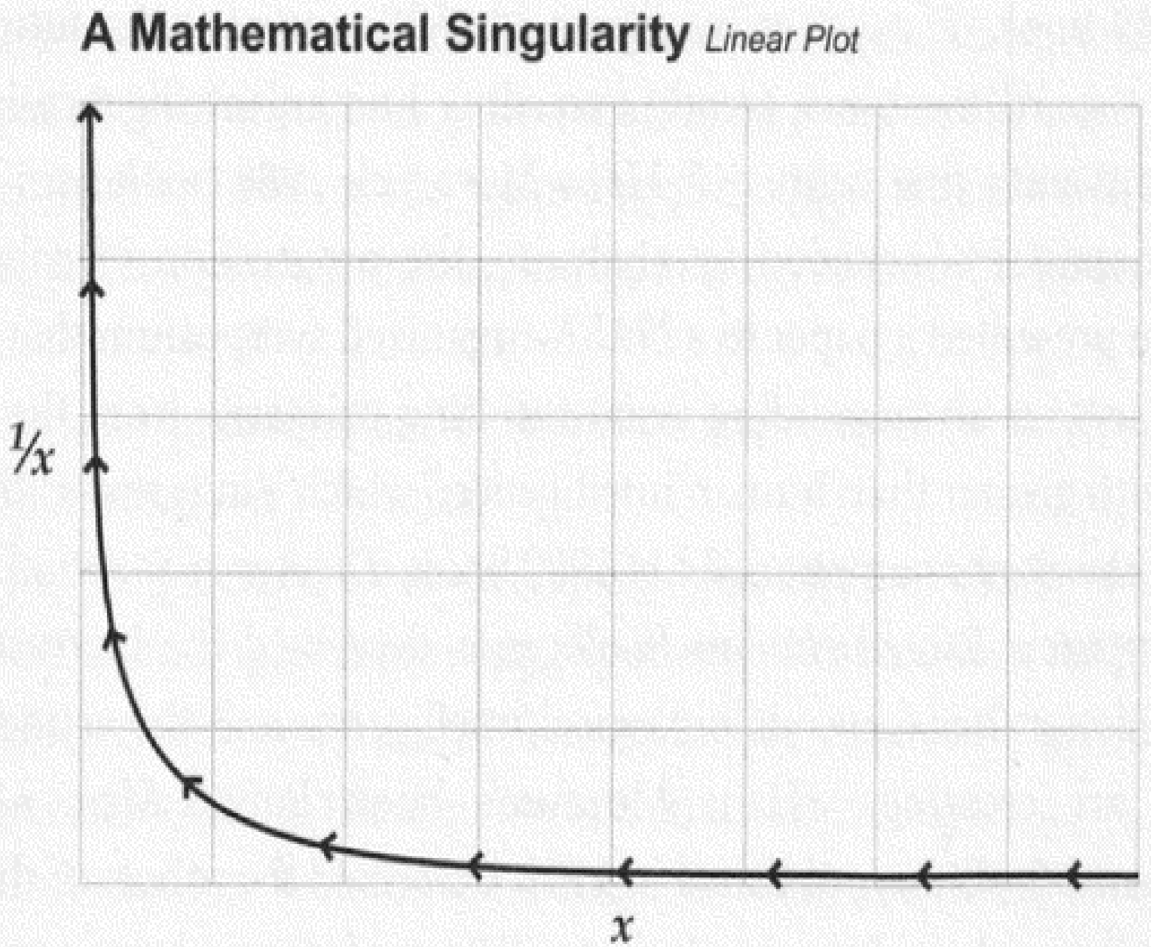
First multicellular life
First Eukaryotes
Life on Earth
-4 000 000 000
-3 000 000 000
-2 000 000 000
-1 000 000 000
0
t



Macrodevelopment rate (frequency of phase transitions per year)
1,E+00
1,E-01
1,E-02
1,E-03
1,E-04
1,E-05
1,E-06
1,E-07
1,E-08
1,E-09
1,E-10
y = 2,054x^-1,003
R² = 0,9989
Singularity date = 2029 CE
0 1 2 3 4 5 6 7 8 9 10
Billions of years before the Singularity

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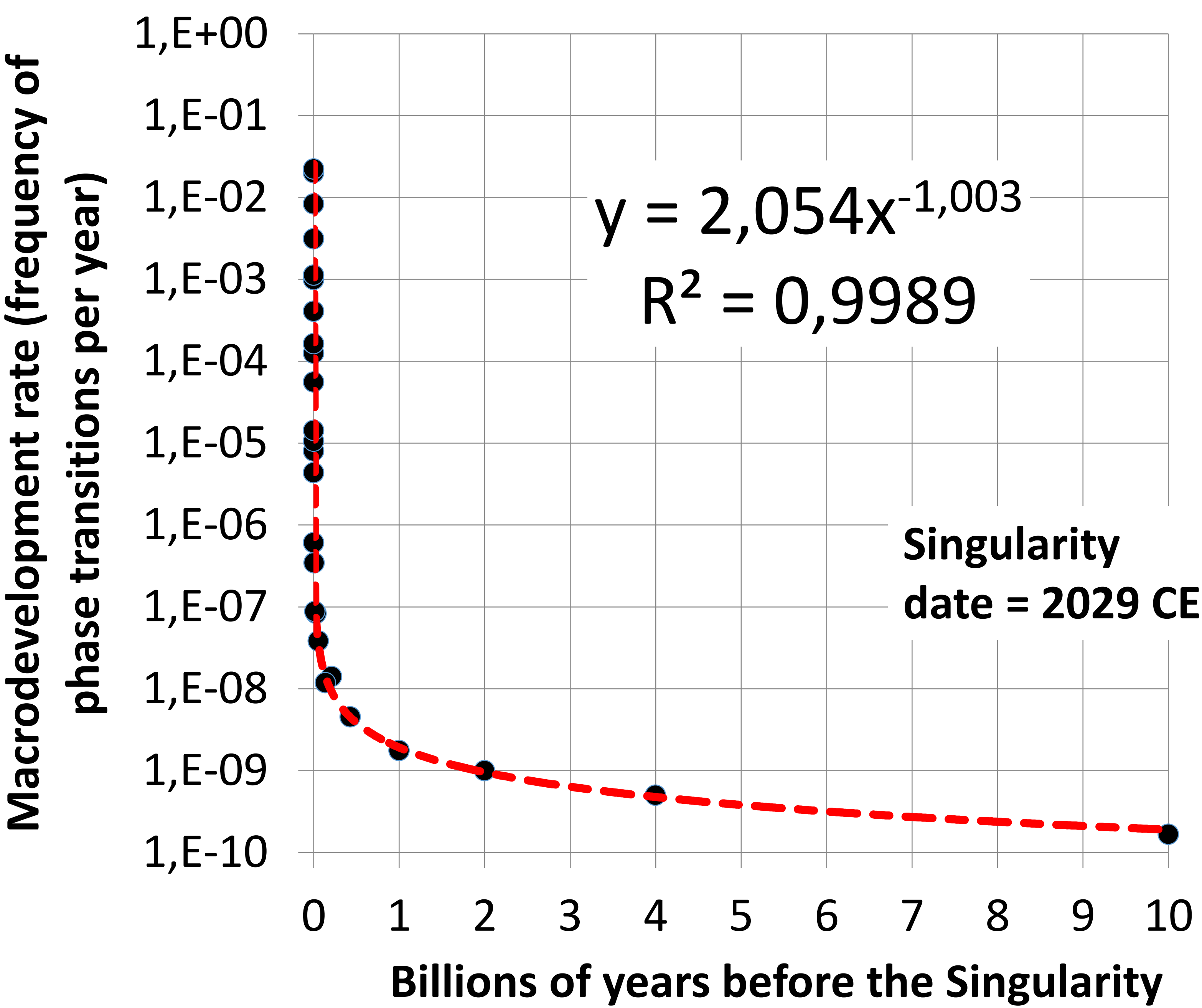
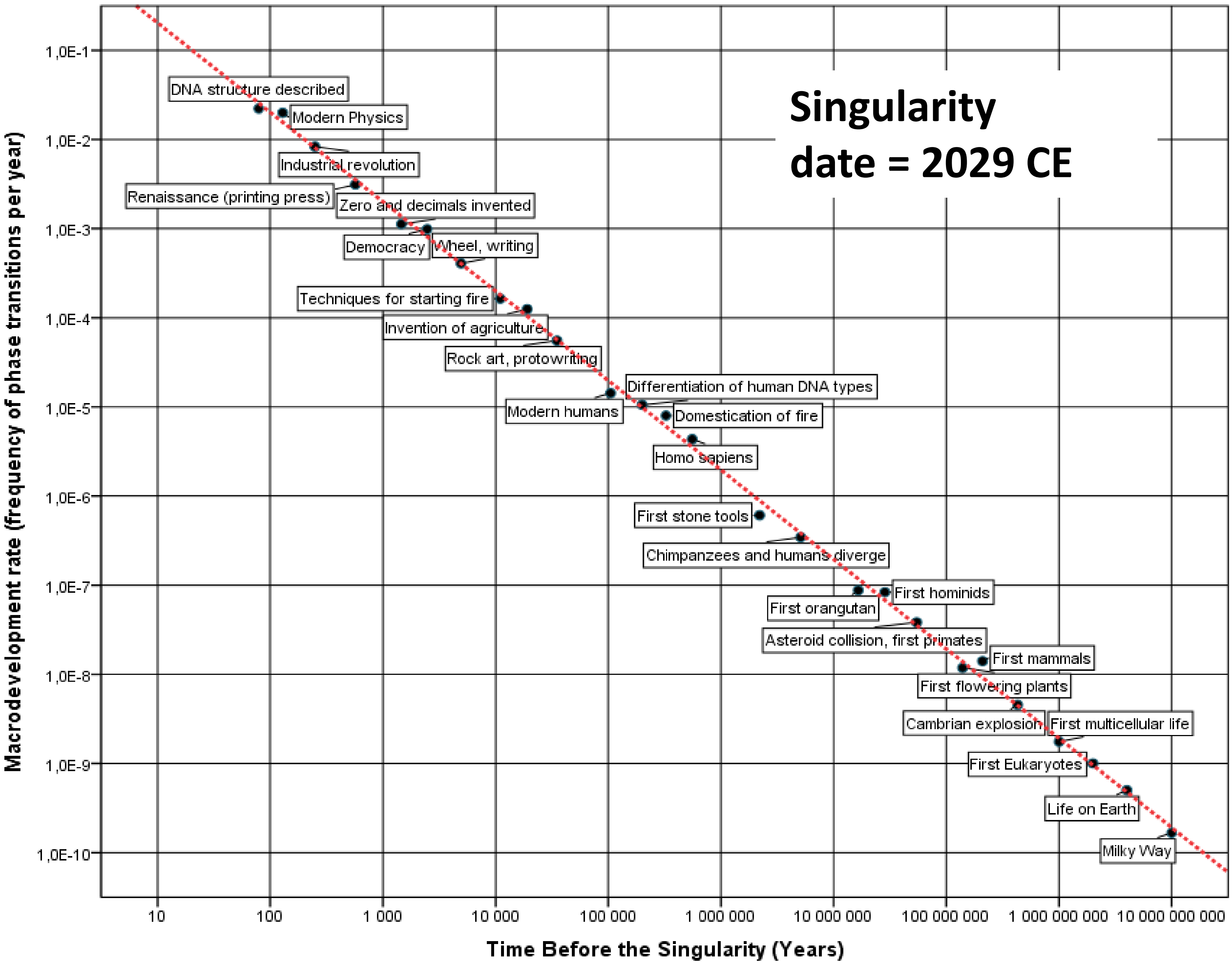


Macrodevelopment rate (frequency of phase transitions per year)
1,E+00
1,E-01
1,E-02
1,E-03
1,E-04
1,E-05
1,E-06
1,E-07
1,E-08
1,E-09
1,E-10
0 1 2 3 4 5 6 7 8 9 10
Billions of years before the Singularity
y = 2,054x^-1,003
R^2 = 0,9989
Singularity date = 2029 CE


Singularity
date = 2029 CE
DNA structure described
Modern Physics
Industrial revolution
Renaissance (printing press)
Zero and decimals invented
Democracy
Wheel, writing
Techniques for starting fire
Invention of agriculture
Rock art, protowriting
Differentiation of human DNA types
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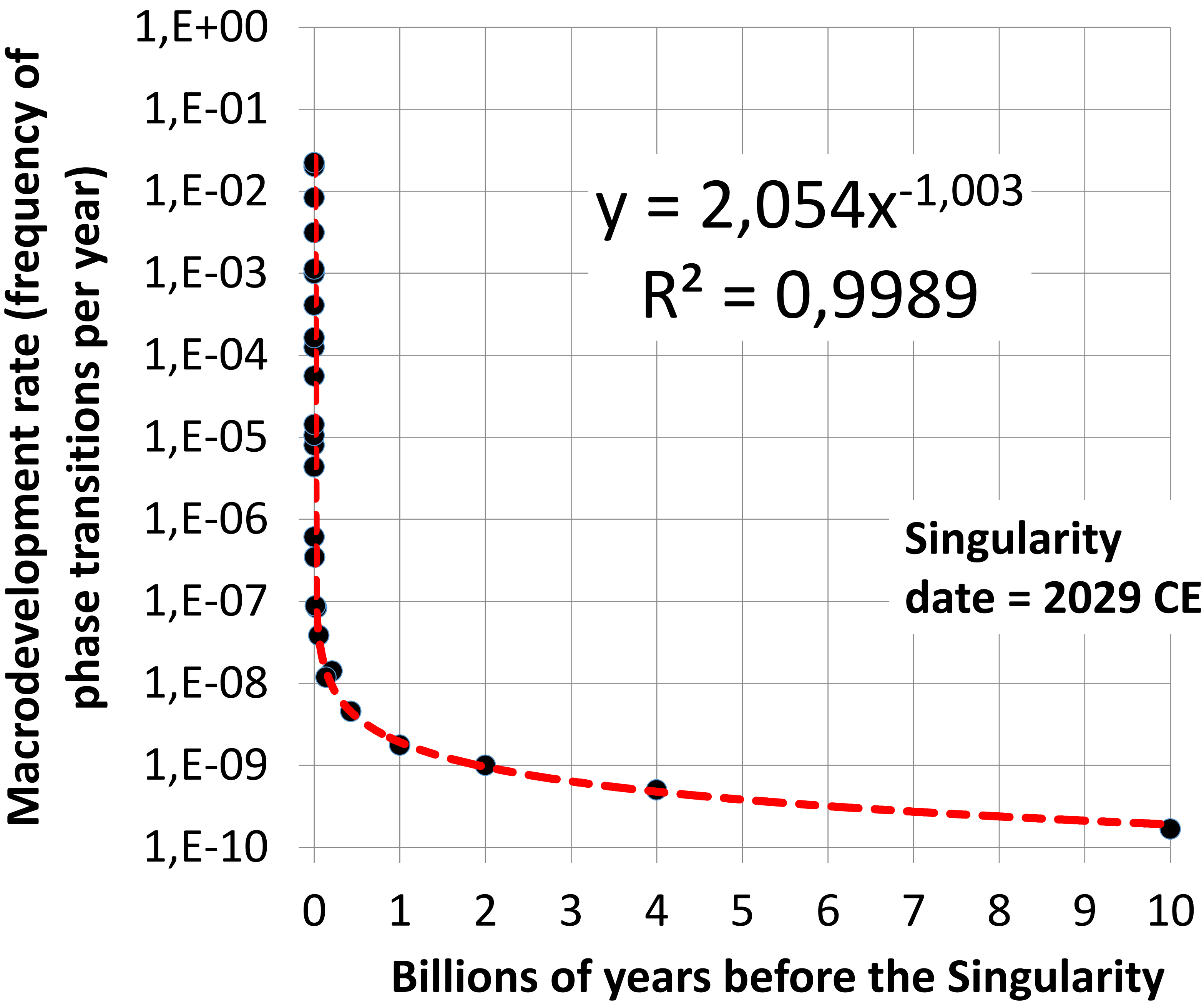
Domestication of fire
Homo sapiens
First stone tools
Chimpanzees and humans diverge
First hominids
First orangutan
Asteroid collision, first primates
First mammals
First flowering plants
Cambrian explosion
First multicellular life
First Eukaryotes
Life on Earth
Milky Way
Macrodevelopment rate (frequency of phase transitions per year)
1,0E-1
1,0E-2
1,0E-3
1,0E-4
1,0E-5
1,0E-6
1,0E-7
1,0E-8
1,0E-9
1,0E-10
10
100
1 000
10 000
100 000
1 000 000
10 000 000
100 000 000
1 000 000 000
10 000 000 000
Time Before the Singularity (Years)

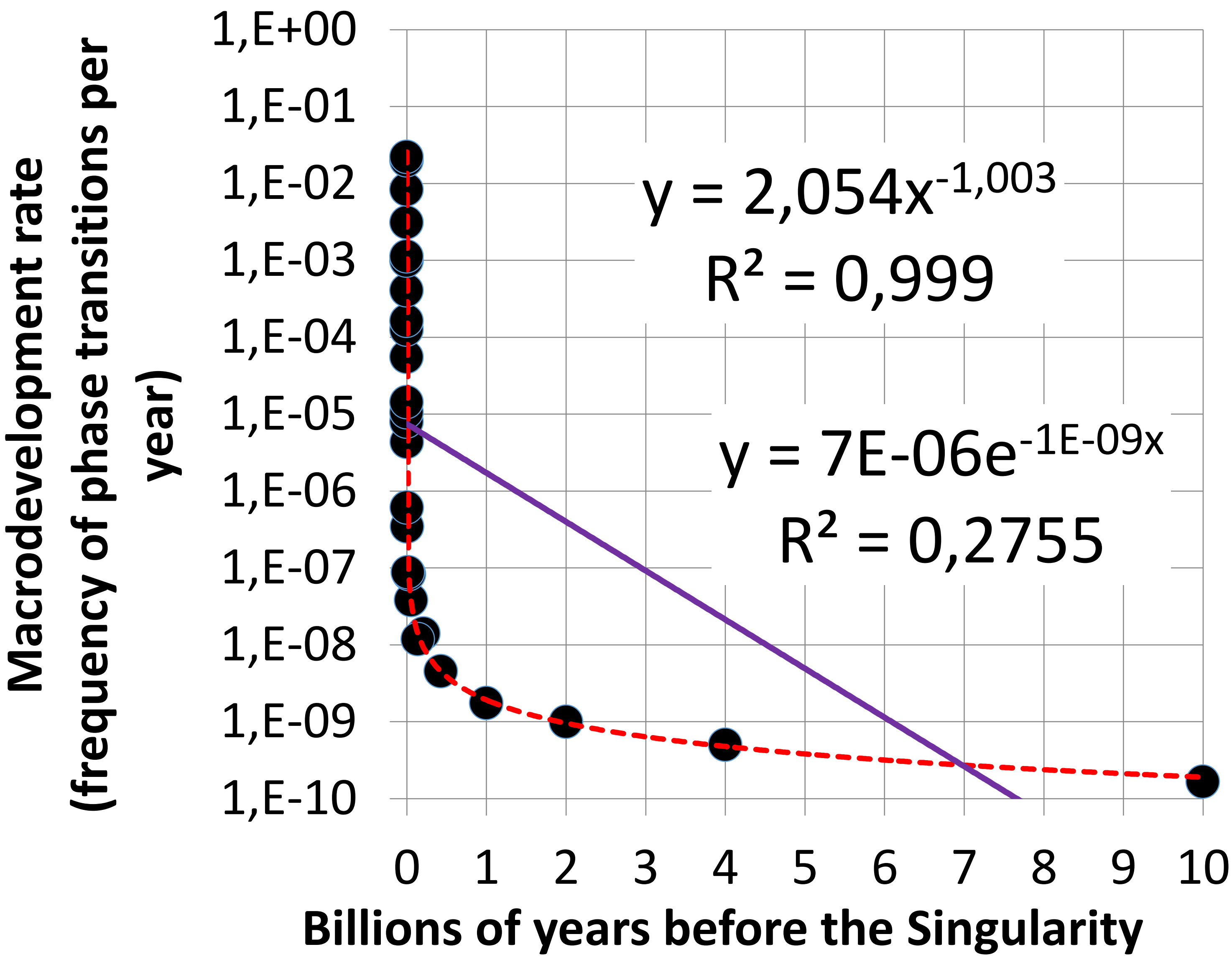


Macrodevelopment rate (frequency of phase transitions per year)
1,E+00
1,E-01
1,E-02
1,E-03
1,E-04
1,E-05
1,E-06
1,E-07
1,E-08
1,E-09
1,E-10
y = 2,054x-1,003
R2 = 0,9989
Singularity date = 2029 CE
0
1
2
3
4
5
6
7
8
9
10
Billions of years before the Singularity

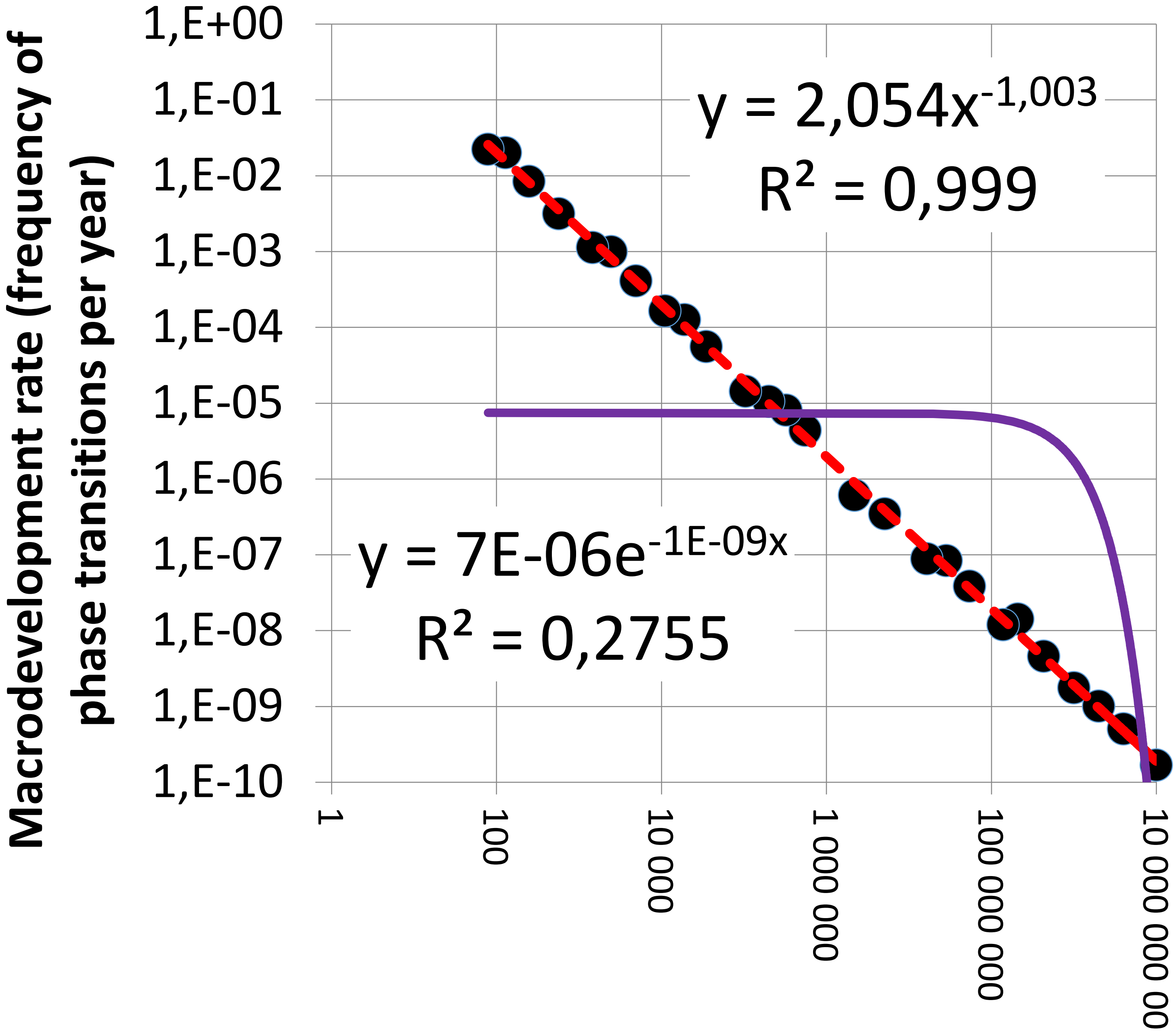
$y = k/x$

$$y = \frac{2.054}{x^{1.003}}$$

$$y = \frac{2.054}{x}$$



Macrodevelopment rate
(frequency of phase transitions per year)
1,E+00
1,E-01
1,E-02
1,E-03
1,E-04
1,E-05
1,E-06
1,E-07
1,E-08
1,E-09
1,E-10
y = 2,054x^-1,003
R² = 0,999
y = 7E-06e^-1E-09x
R² = 0,2755
0 1 2 3 4 5 6 7 8 9 10
Billions of years before the Singularity



Macrodevelopment rate (frequency of phase transitions per year)
1,E+00
1,E-01
1,E-02
1,E-03
1,E-04
1,E-05
1,E-06
1,E-07
1,E-08
1,E-09
1,E-10
1
100
10 000
1 000 000
100 000 000
10 000 000 00
y = 2,054x-1,003
R² = 0,999
y = 7E-06e-1E-09x
R² = 0,2755

$$y = \frac{2.054}{x}$$

$x = t^* - t$

$$y_t = \frac{2.054}{2029 - t}$$

$$y_t = \frac{C}{t^* - t}$$

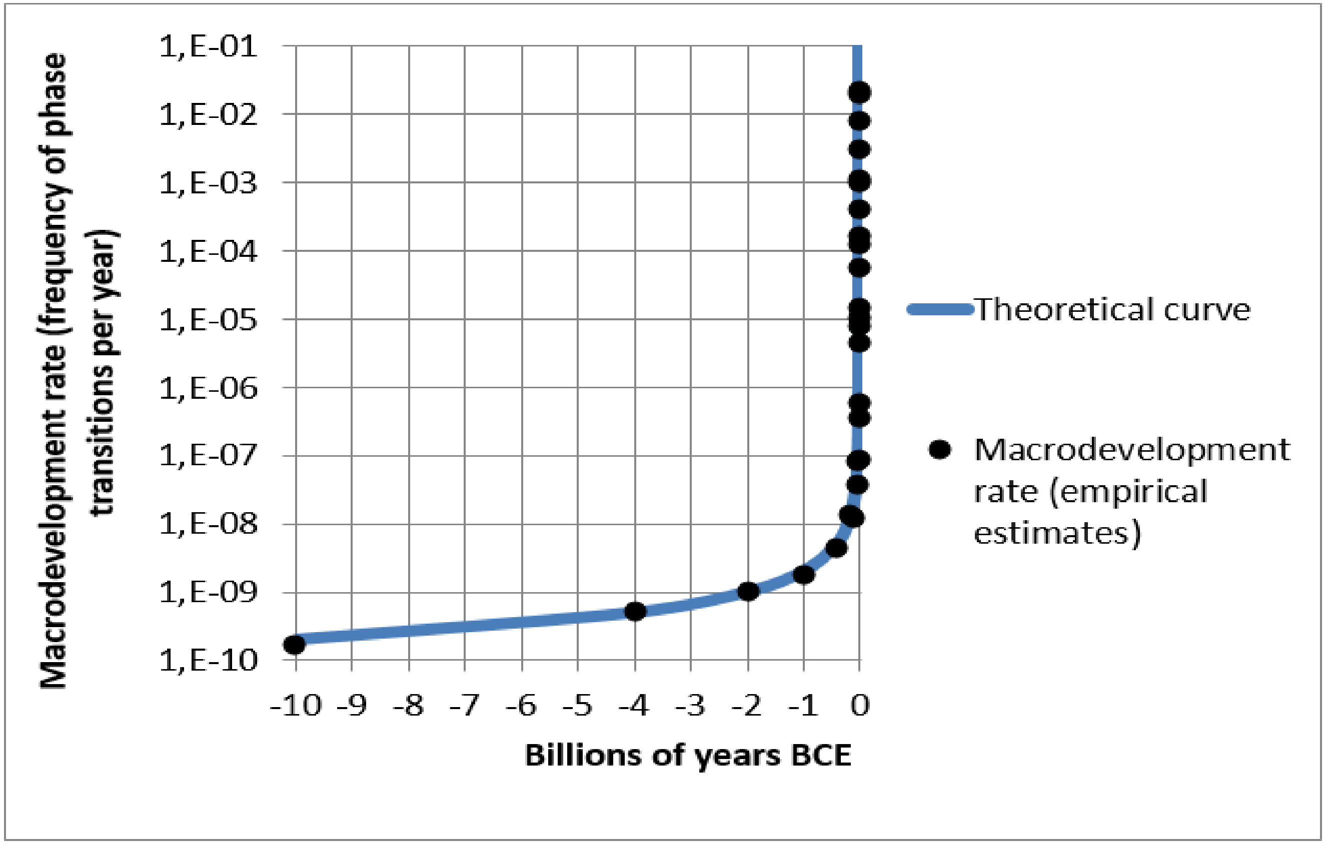



**Fig. 13.** Fit between the empirical estimates of the macrodevelopment rate and the theoretical curve generated by the hyperbolic equation $y_t = 2.054/(2029\text{-}t)$, 10 billion BCE – 2000 CE, with a logarithmic scale for the Y-axis

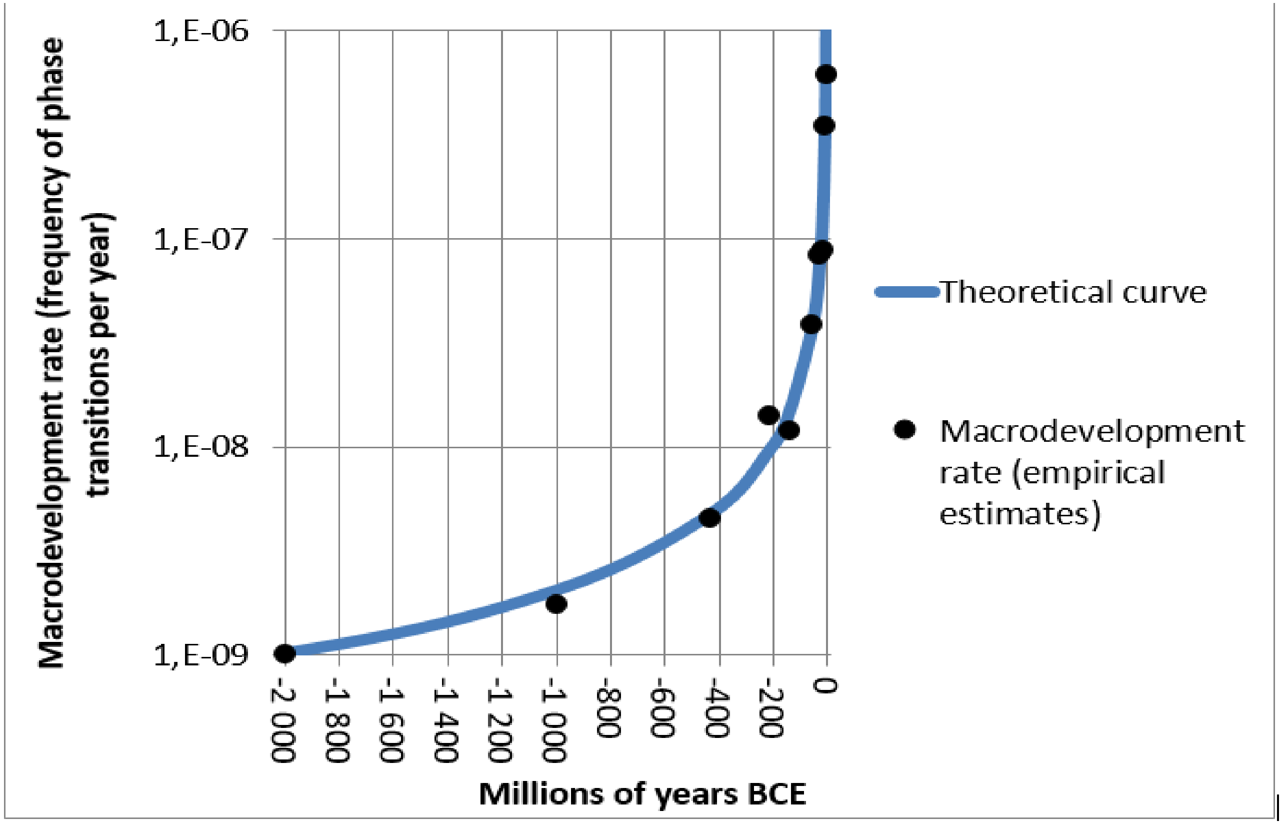



**Fig. 14.** Fit between the empirical estimates of the macrodevelopment rate and the theoretical curve generated by the hyperbolic equation $y_t = 2.054/(2029\text{-}t)$, 2 billion – 2 200 000 CE, with a logarithmic scale for the Y-axis

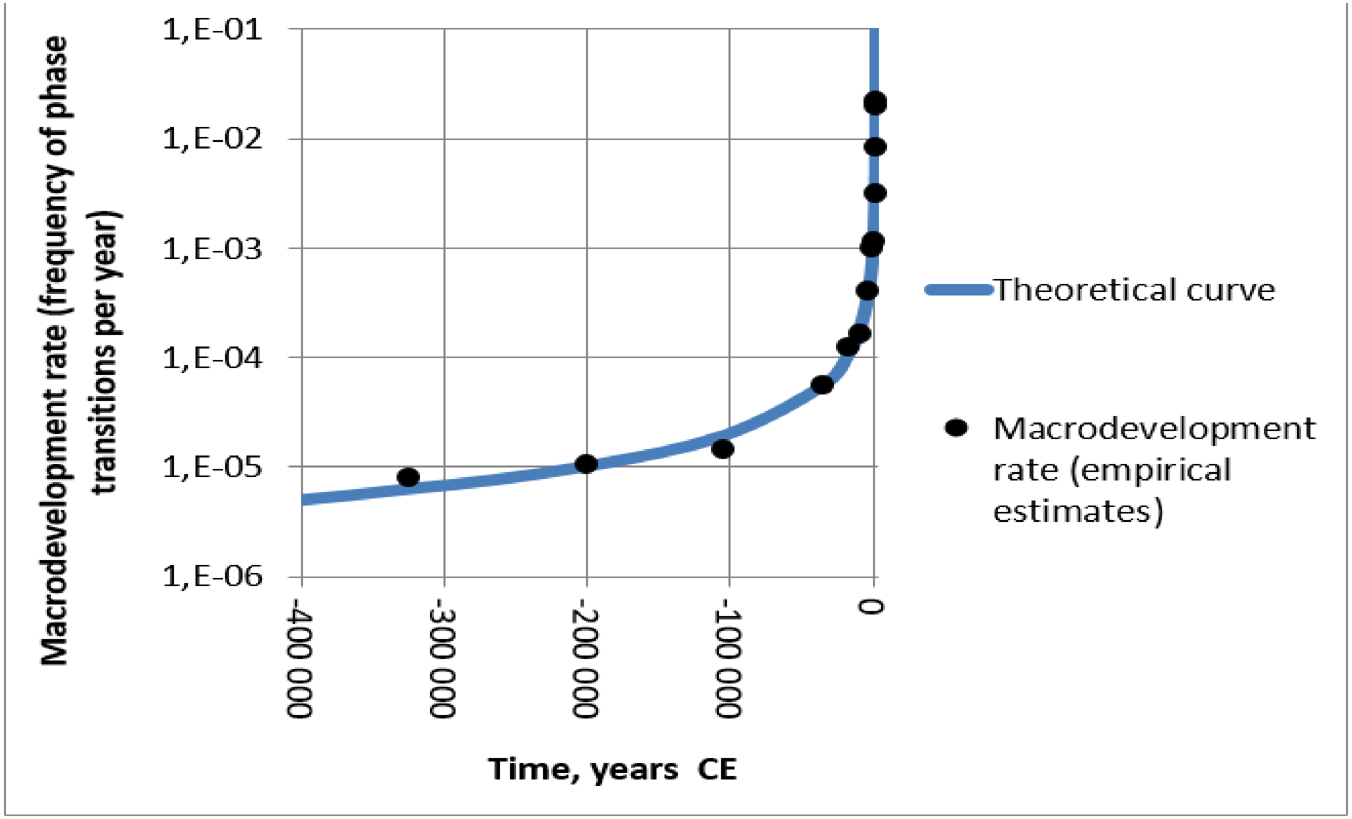



**Fig. 15.** Fit between the empirical estimates of the macrodevelopment rate and the theoretical curve generated by the hyperbolic equation $y_t = 2.054/(2029\text{-}t)$, 400 000 BCE – 2000 CE, with a logarithmic scale for the Y-axis

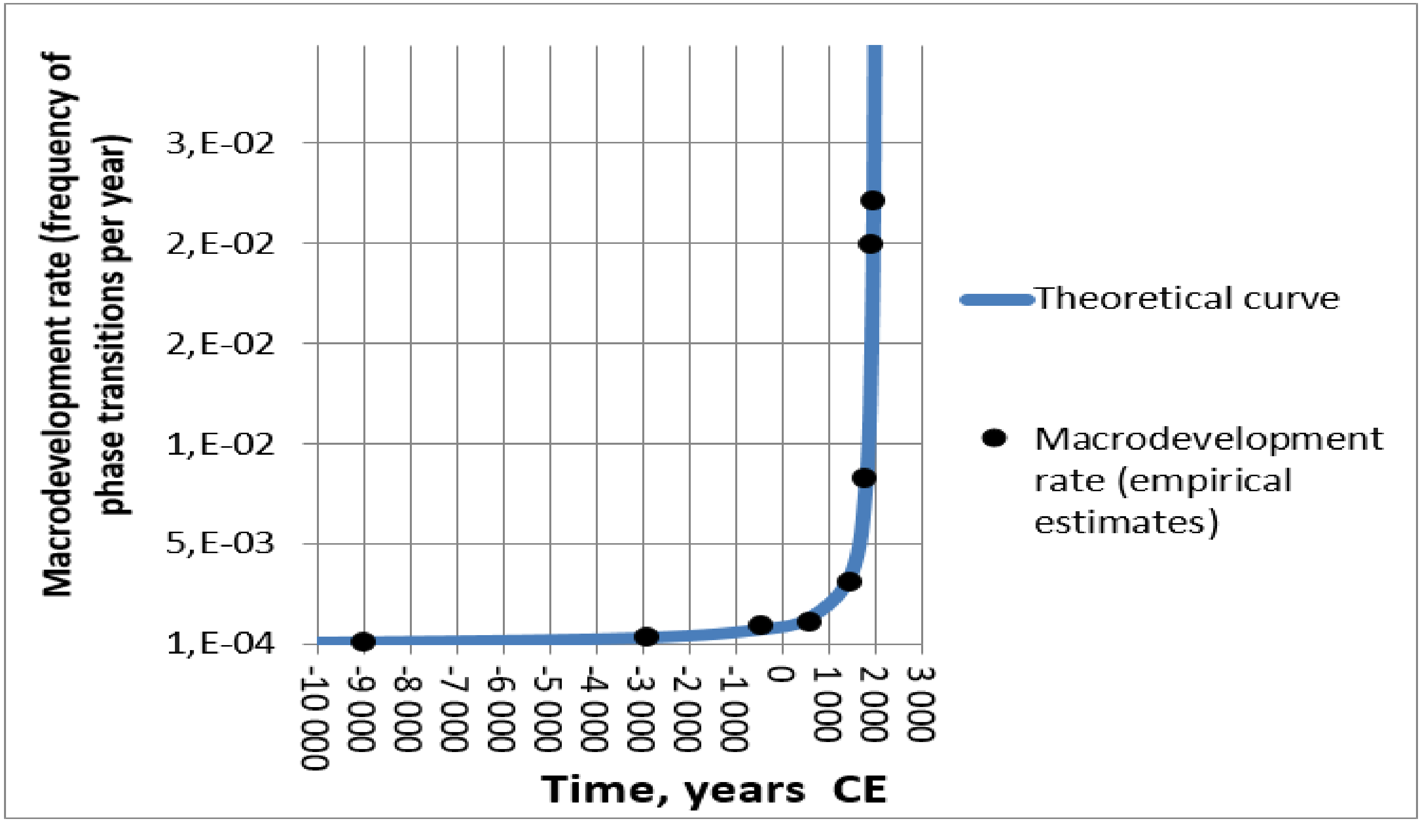
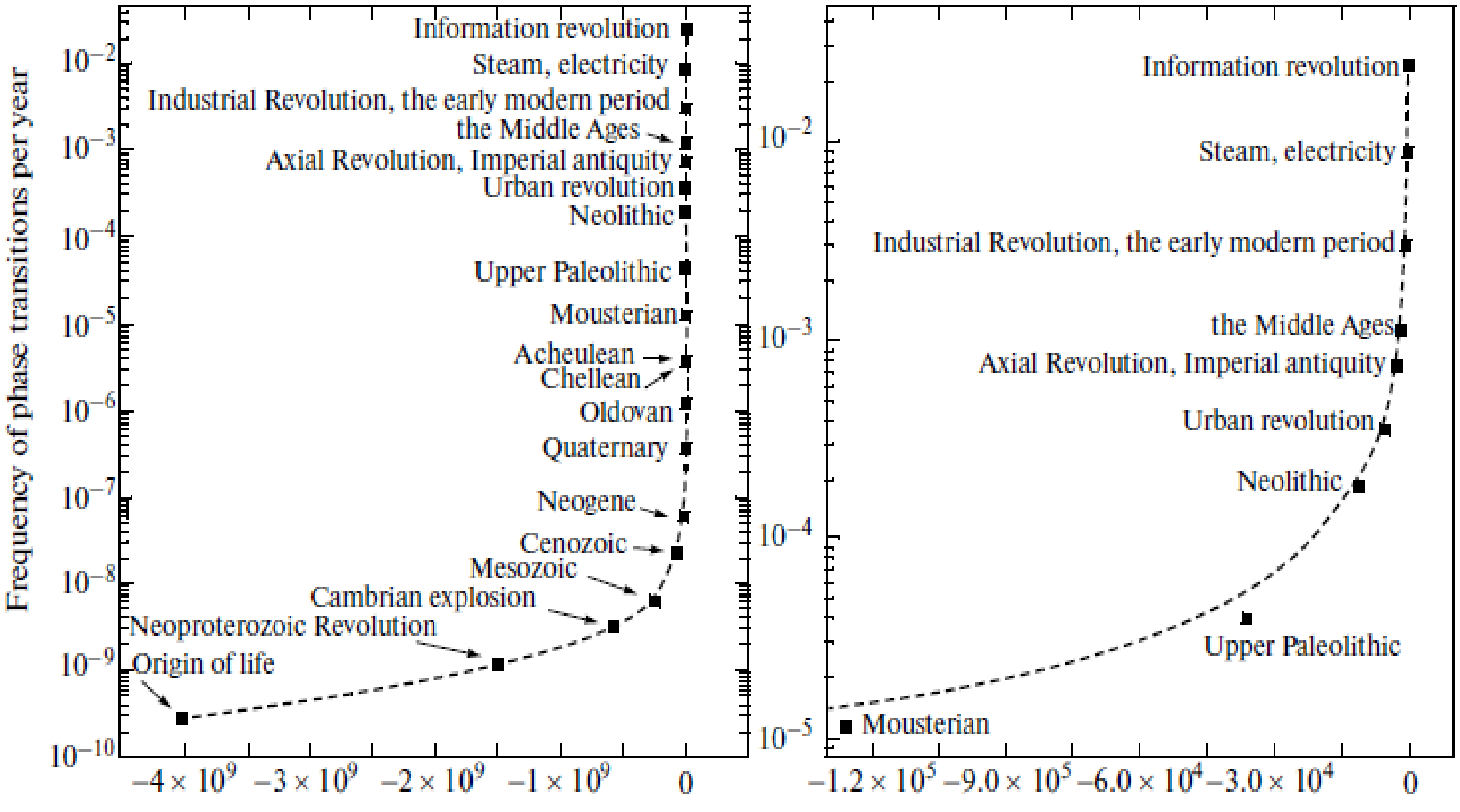



**Fig. 16.** Fit between the empirical estimates of the macrodevelopment rate and the theoretical curve generated by the hyperbolic equation $y_t = 2.054/(2029\text{-}t)$, 10 000 BCE – 2000 CE, with a natural scale for the both axes



Frequency of phase transitions per year
Information revolution
Steam, electricity
Industrial Revolution, the early modern period
the Middle Ages
Axial Revolution, Imperial antiquity
Urban revolution
Neolithic
Upper Paleolithic
Mousterian
Acheulean
Chellean
Oldovan
Quaternary
Neogene
Cenozoic
Mesozoic
Cambrian explosion
Neoproterozoic Revolution
Origin of life
10^−2
10^−3
10^−4
10^−5
10^−6
10^−7
10^−8
10^−9
10^−10
−4 × 10^9
−3 × 10^9
−2 × 10^9
−1 × 10^9
0
Information revolution
Steam, electricity
Industrial Revolution, the early modern period
the Middle Ages
Axial Revolution, Imperial antiquity
Urban revolution
Neolithic
Upper Paleolithic
Mousterian
10^−2
10^−3
10^−4
10^−5
−1.2 × 10^5
−9.0 × 10^5
−6.0 × 10^4
−3.0 × 10^4
0

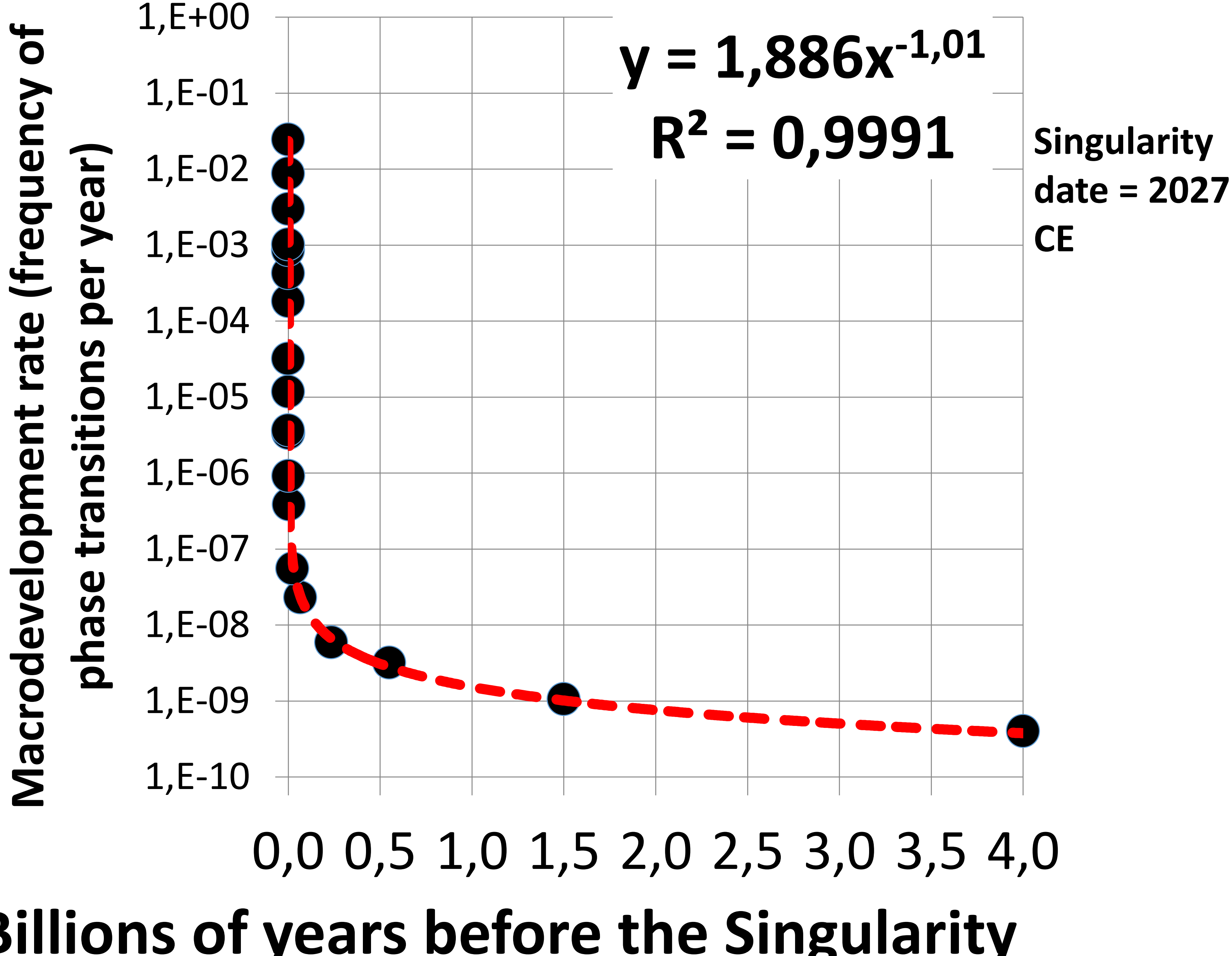
$$t_n = t^* - T/\alpha^n, \text{ or}$$

$$\lg(t^* - t_n) = \lg T - n \lg \alpha,$$

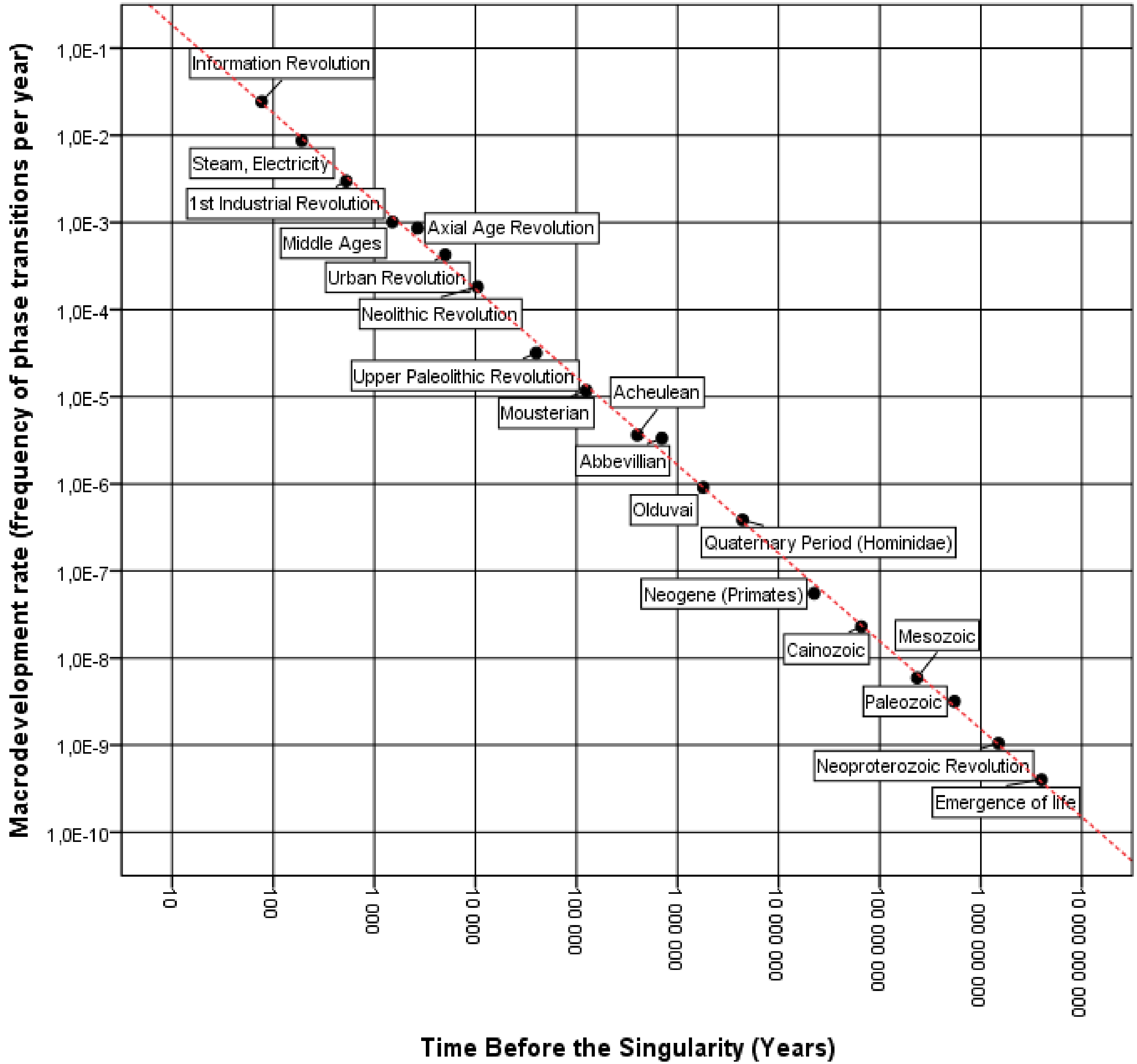
where $n$ is a phase transition/planetary revolution number, $t^*$ is the singularity time, $T$ is the total length of time for the analyzed time series ($4 \times 10^9$ years in Panov's case), and $\alpha$ is a parameter denoted by Panov as "coefficient of acceleration of historical time"

The Singularity time = 2064 (for the human history – starting from the Middle Paleolithic)

The Singularity time = 2004 (for the global history – starting from the origins of life on the Earth)



Macrodevelopment rate (frequency of phase transitions per year)
1,E+00
1,E-01
1,E-02
1,E-03
1,E-04
1,E-05
1,E-06
1,E-07
1,E-08
1,E-09
1,E-10
y = 1,886x-1,01
R² = 0,9991
Singularity date = 2027 CE
0,0
0,5
1,0
1,5
2,0
2,5
3,0
3,5
4,0
Billions of years before the Singularity


Macrodevelopment rate (frequency of phase transitions per year)
1,0E-1
1,0E-2
1,0E-3
1,0E-4
1,0E-5
1,0E-6
1,0E-7
1,0E-8
1,0E-9
1,0E-10
Information Revolution
Steam, Electricity
1st Industrial Revolution
Middle Ages
Axial Age Revolution
Urban Revolution
Neolithic Revolution
Upper Paleolithic Revolution
Mousterian
Acheulean
Abbevillian
Olduvai
Quaternary Period (Hominidae)
Neogene (Primates)
Cainozoic
Mesozoic
Paleozoic
Neoproterozoic Revolution
Emergence of life
10
100
1 000
10 000
100 000
1 000 000
10 000 000
100 000 000
1 000 000 000
10 000 000 000
Time Before the Singularity (Years)

$$\boldsymbol{y = \frac{1.886}{x^{1.01}}}$$

$$\boldsymbol{y = \frac{1.886}{x}}$$

$$\boldsymbol{y_t = \frac{1.886}{2027 - t}}$$

$$\boldsymbol{y_t = \frac{C}{t^* - t}}$$

## Von Foerster showed that between 1 and 1958 CE the world's population (*N*) dynamics can be described in an extremely accurate way with an astonishingly simple equation:

$$N_t = \frac{C}{(t^* - t)^{0.99}}$$

where $N_t$ is the world population at time $t$, and $C$ and $t_0$ are constants, with $t_0$ corresponding to an absolute limit ("singularity" point) at which $N$ would become infinite.

Parameter $t_0$ was estimated by von Foerster and his colleagues as 2026.87, which corresponds to November 13, 2026; this made it possible for them to supply their article with a public-relations masterpiece title:

**"Doomsday: Friday, 13 November, A.D. 2026"**

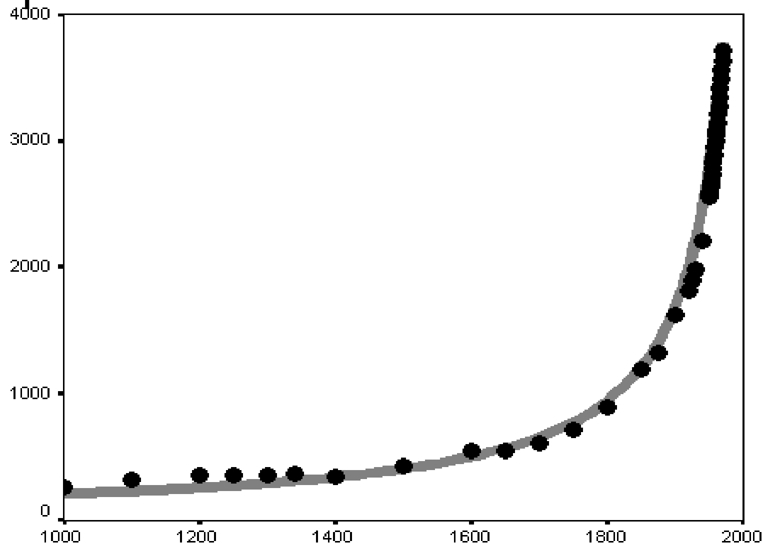
What is especially important for us is that, as was the case with equation (1) above, the denominator's exponent (0.99) turned out to be only negligibly different from 1, and as has been shown by von Hoerner (1975) and Kapitza (1992, 1999), it can be written more succinctly as

$$N_t = \frac{C}{t^* - t}$$

**2026.87 ≈ 2027**

$$N_t = \frac{C}{2027 - t}$$

The overall correlation between the curve generated by von Foerster's equation and the most detailed series of empirical estimates looks as follows:




$$N_t = \frac{C}{2027 - t}$$

The formal characteristics are as follows:
$R$ = 0.998; $R^2$ = 0.996; $p$ = 9.4 × $10^{-17}$ ≈ 1 × $10^{-16}$.

Thus, von Foerster's equation accounts for an astonishing 99.6% of all the macrovariation in world population, from 1000 CE through 1970, as estimated by McEvedy and Jones (1978) and the U.S. Bureau of the Census (2006).

Note also that the empirical estimates of world population find themselves aligned in an extremely neat way along the hyperbolic curve, which convincingly justifies the designation of the pre-1970s world population growth pattern as "hyperbolic".

The von Foerster equation, $N_t = \frac{C}{t_0 - t}$

is just the solution for the following differential equation:

$$\frac{dN}{dt} = \frac{N^2}{C}$$

This equation can be also written as:

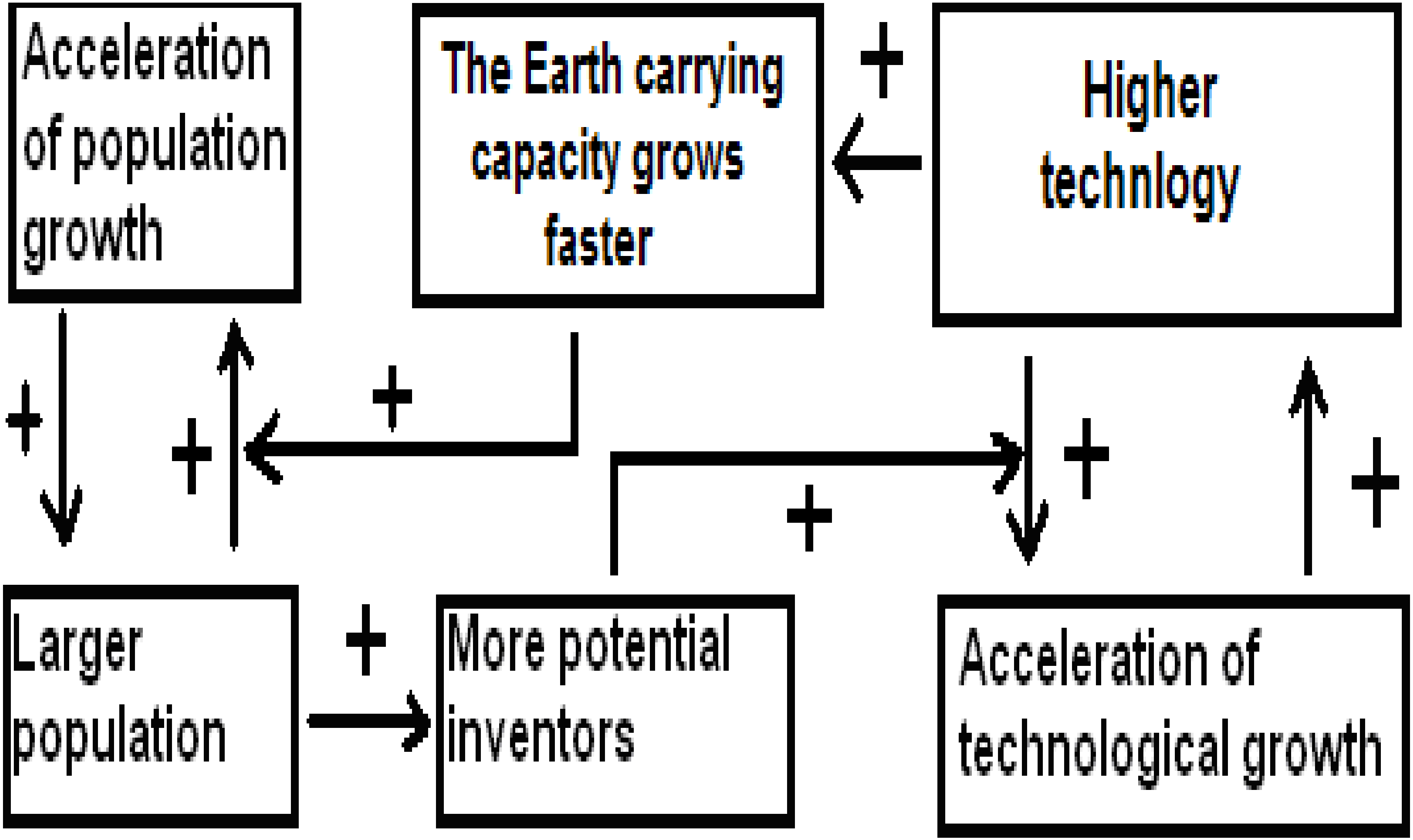
$$\frac{dN}{dt} = aN^2, \text{ where } a = \frac{1}{C}$$

In our context *dN/dt* denotes the absolute population growth rate at some moment of time. Hence, this equation states that the absolute population growth rate at any moment of time should be proportional to the square of population at this moment.

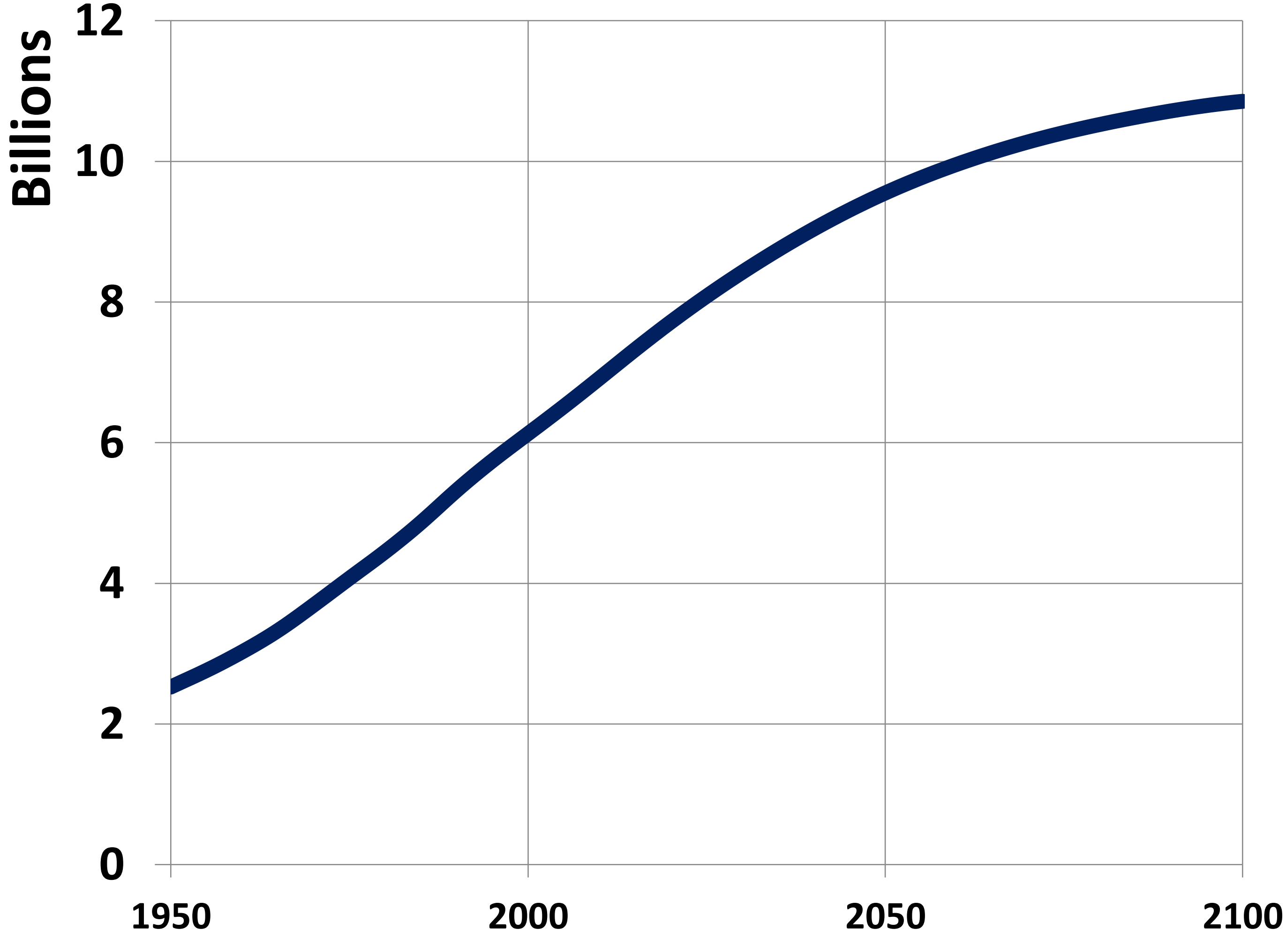
**In fact, the hyperbolic pattern of the world's population growth could be accounted for by the nonlinear second order positive feedback mechanism that was shown long ago to generate just the hyperbolic growth, known also as the "blow-up regime".**

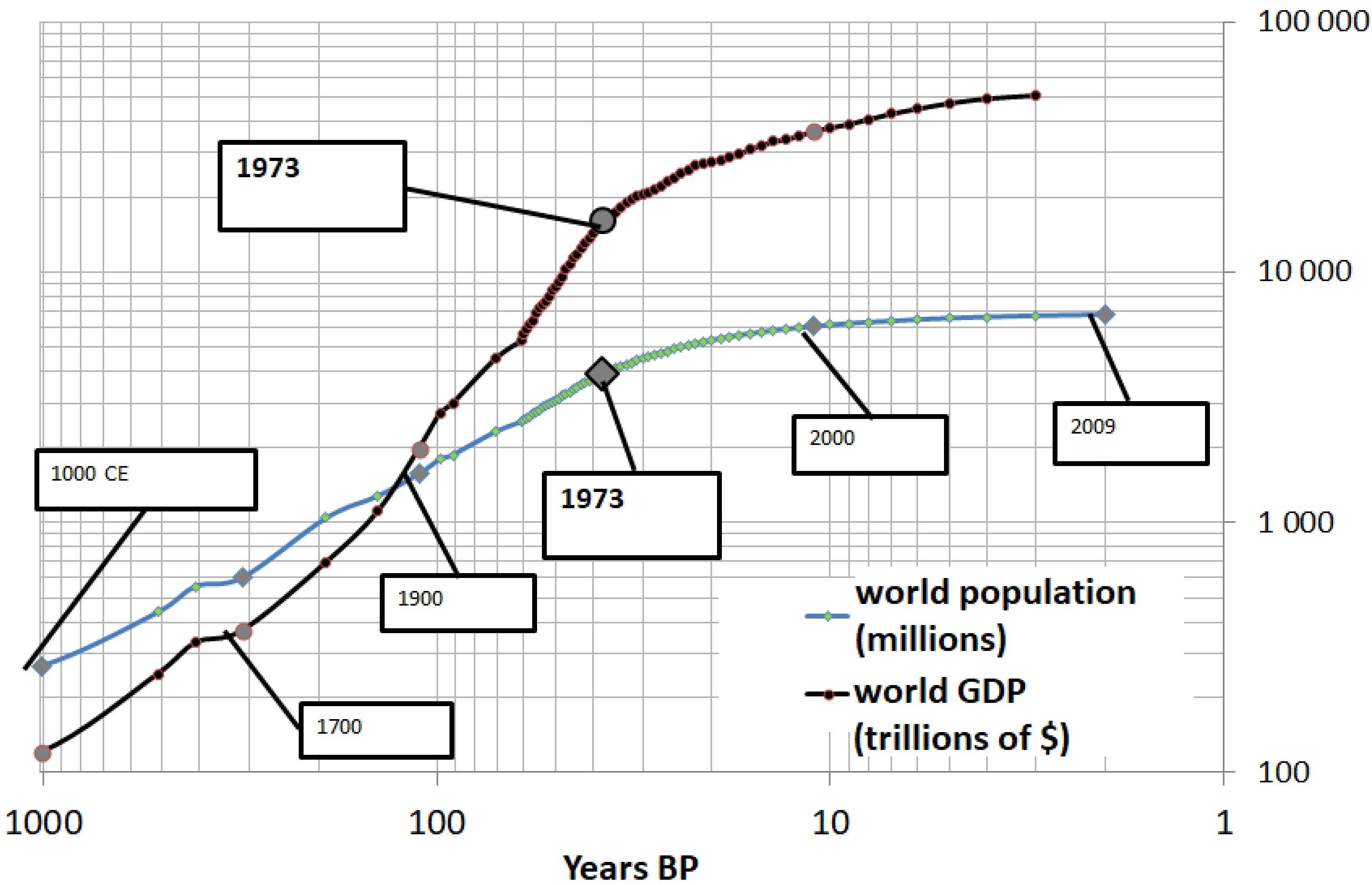
**In our case this nonlinear second order positive feedback looks as follows:**

**the more people – the more potential inventors – the faster technological growth – the faster growth of the Earth's carrying capacity – the faster population growth – with more people you also have more potential inventors – hence, faster technological growth, and so on.**

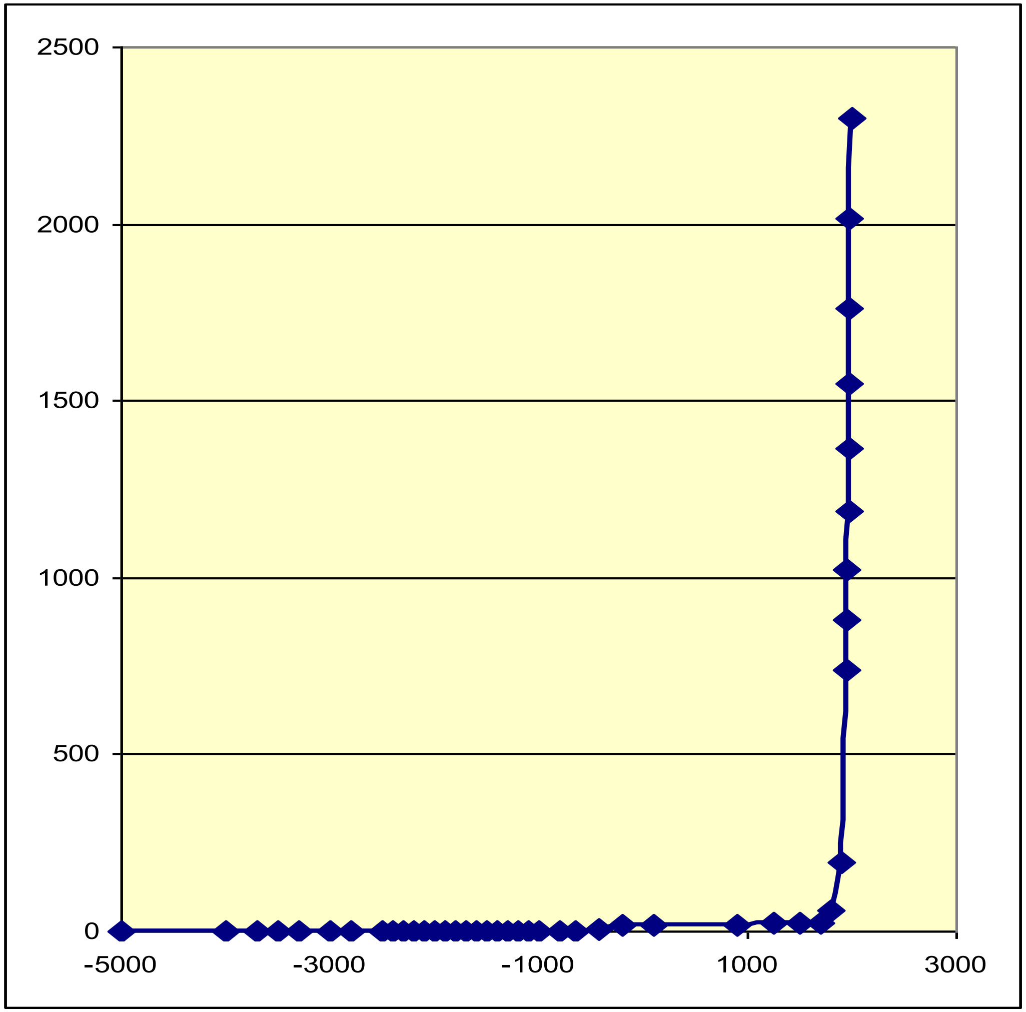


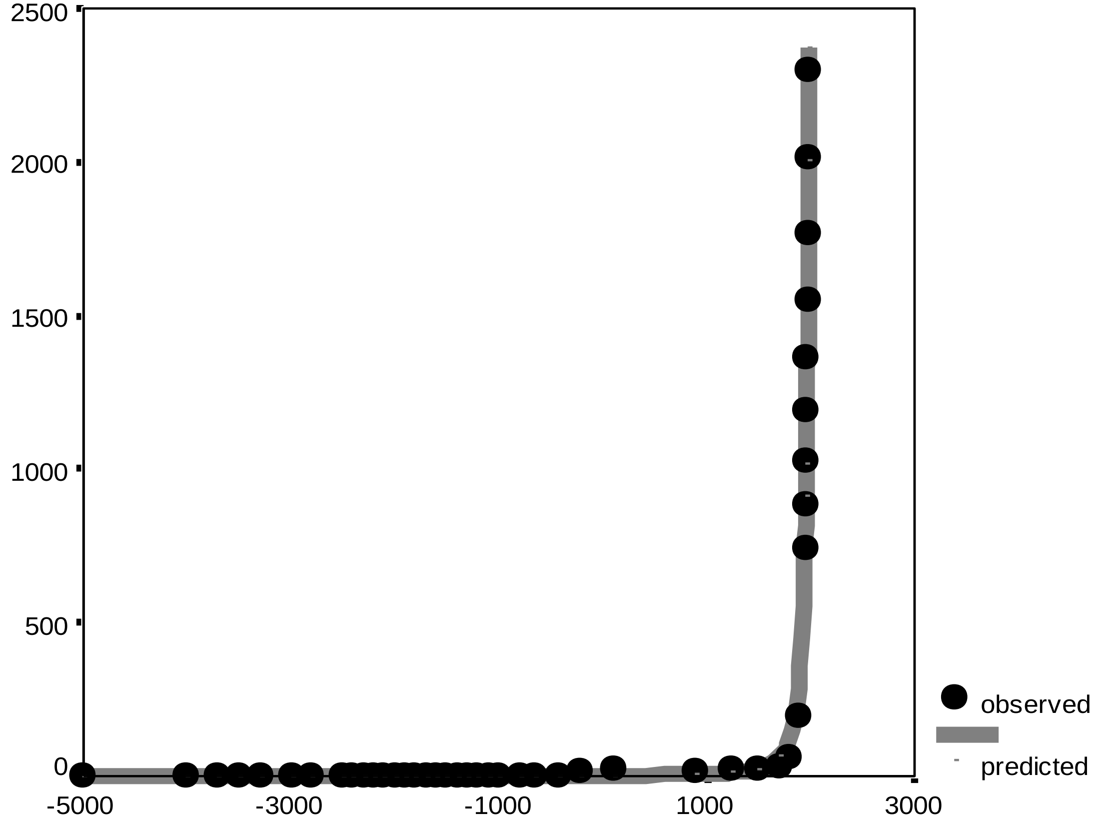
# World population dynamics – empirical estimates (till 2015) and middle forecast till 2100 of the UN Population Division



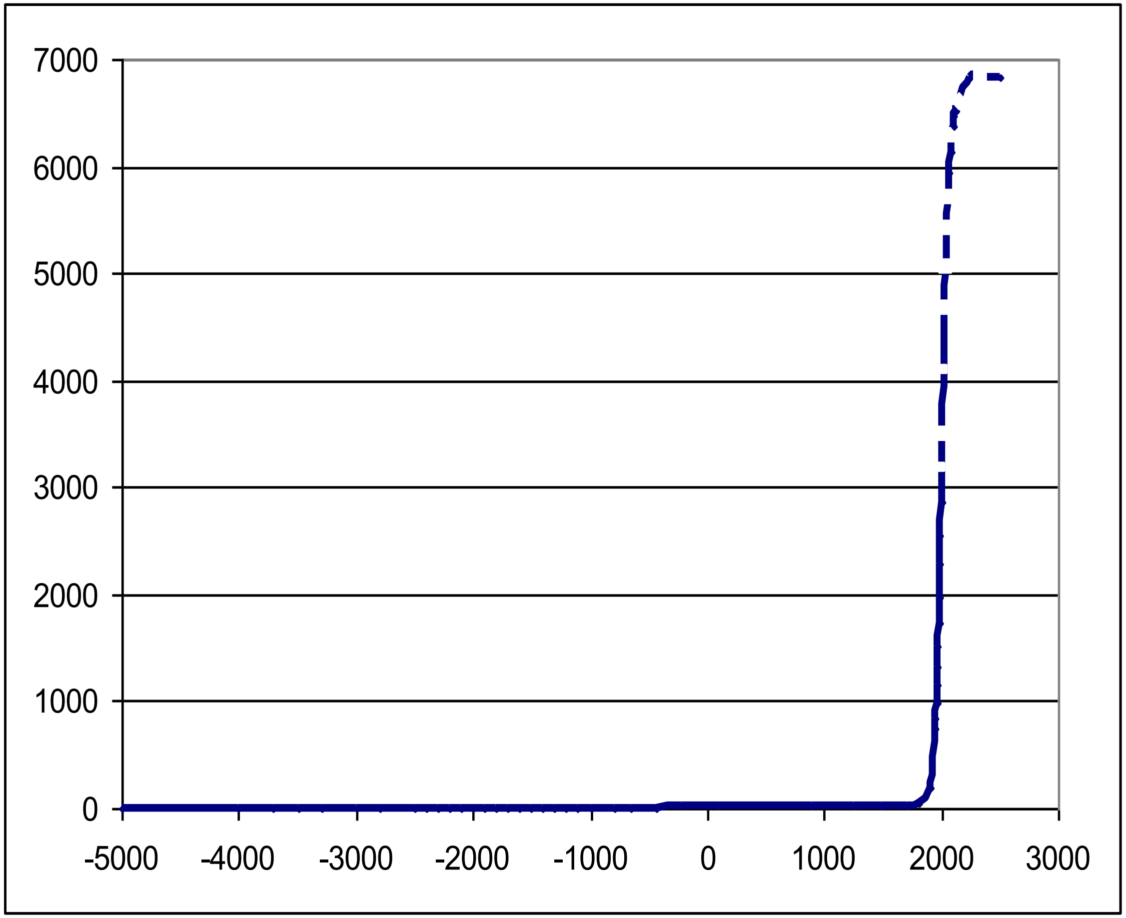


100 000
10 000
1 000
100
1973
1973
1000 CE
1900
1700
2000
2009
world population (millions)
world GDP (trillions of $)
1000
100
10
1
Years BP


2500
2000
1500
1000
500
0
-5000
-3000
-1000
1000
3000




$$U_t = \frac{7705000}{(2047 - t)^2}$$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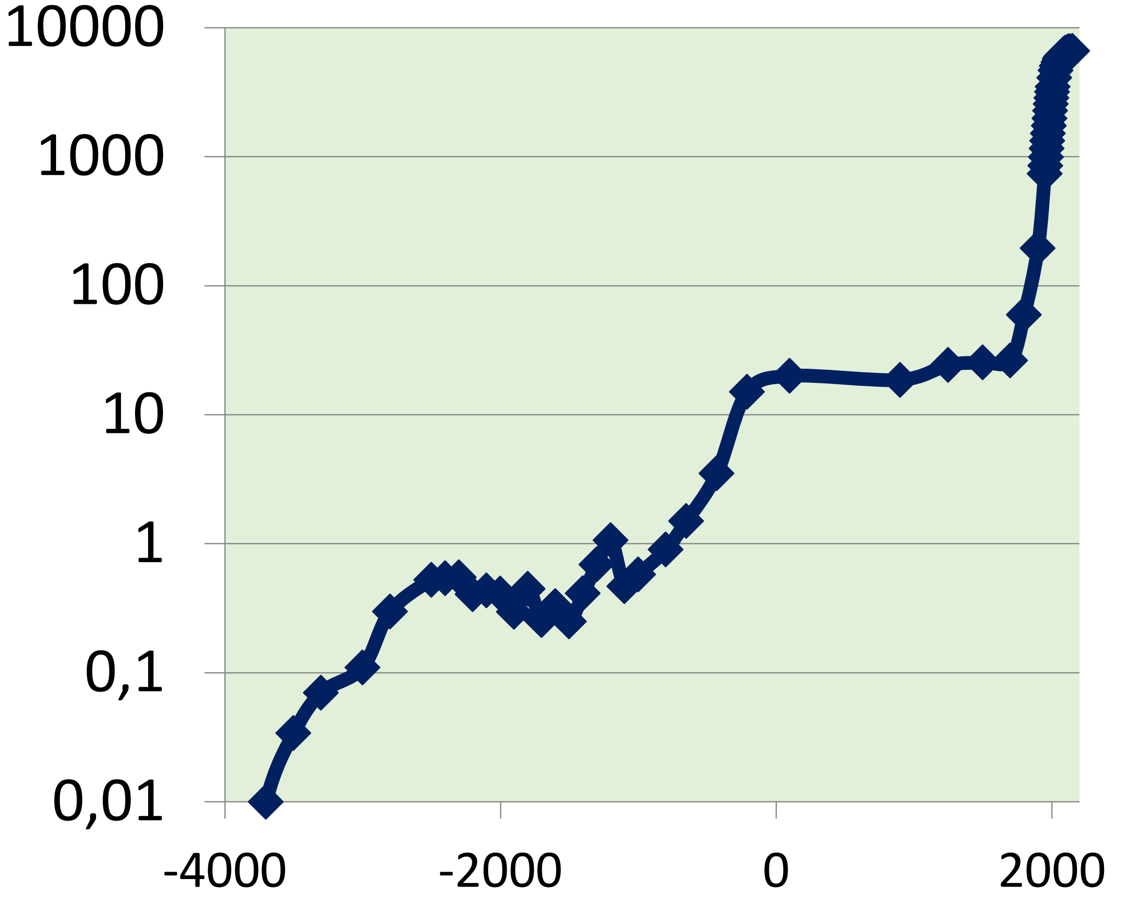
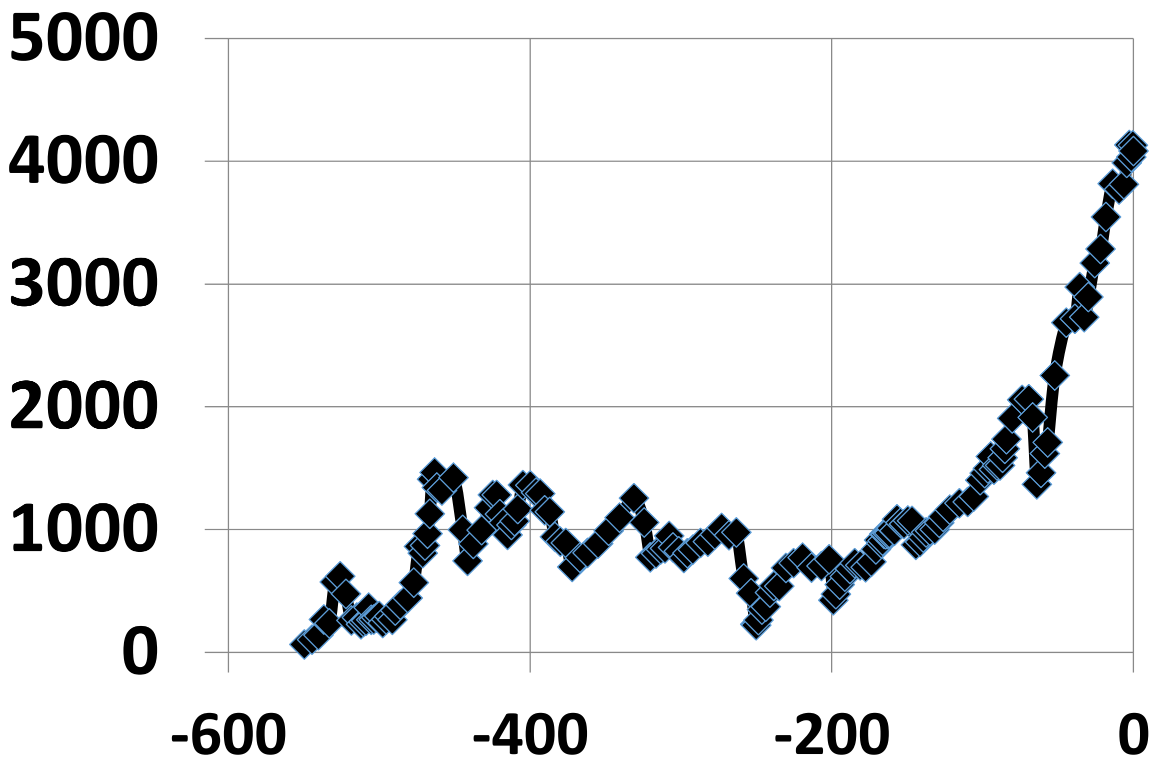
6000
5000
4000
3000
2000
1000
0
-5000
-4000
-3000
-2000
-1000
0
1000
2000
3000



10000
1000
100
10
1
0,1
0,01
-4000
-2000
0
2000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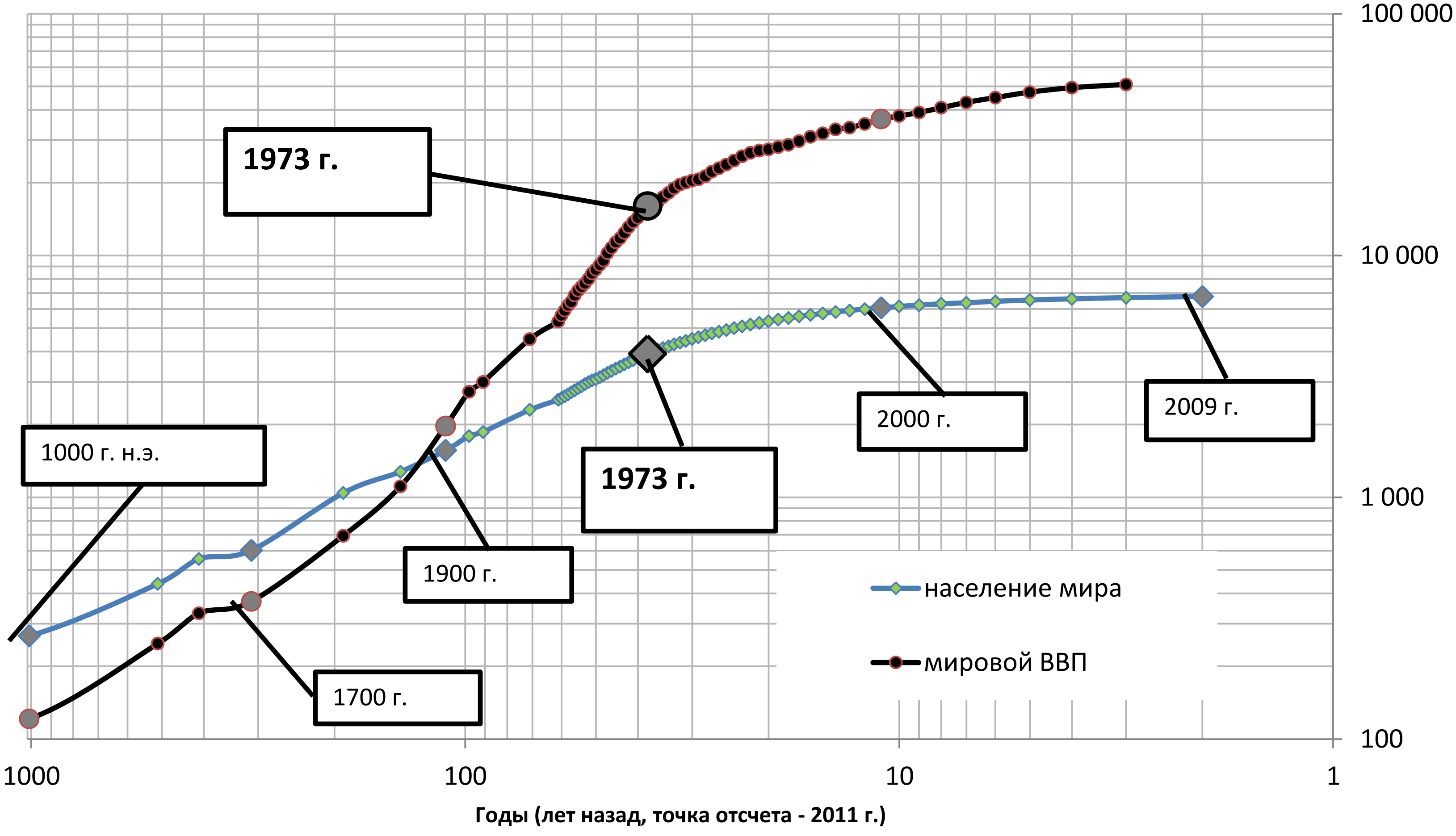
4000
3000
2000
1000
0
-600
-400
-200
0


100 000
10 000
1 000
100
1000
100
10
1
Годы (лет назад, точка отсчета - 2011 г.)
1973 г.
1000 г. н.э.
1900 г.
1973 г.
2000 г.
2009 г.
1700 г.
население мира
мировой ВВП

XIX ВСЕМИРНЫЙ ФЕСТИВАЛЬ МОЛОДЕЖИ И СТУДЕНТОВ

РОССИЯ 2017