Complexity growth patterns in the Big History. Preliminary results of a quantitative analysis

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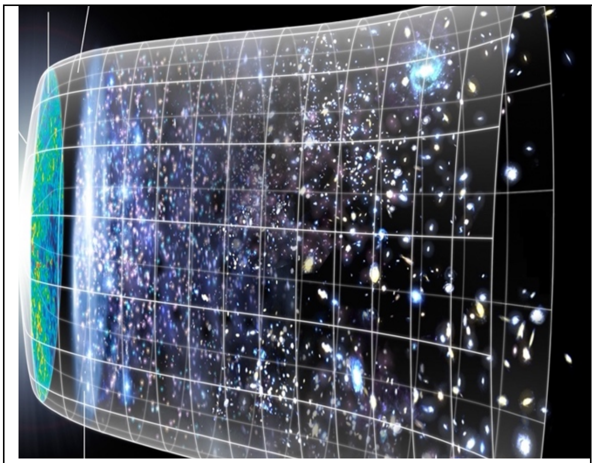
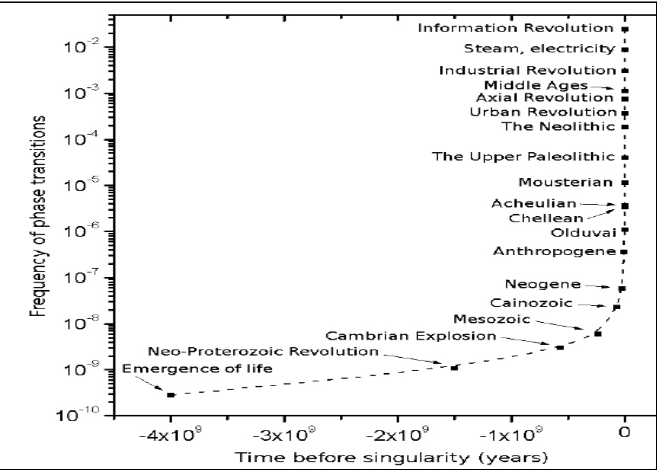
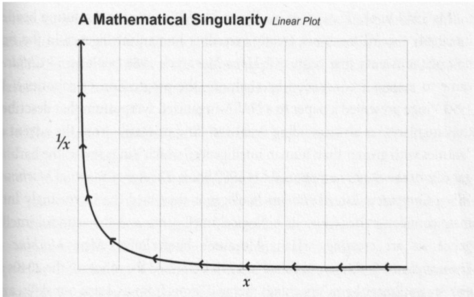


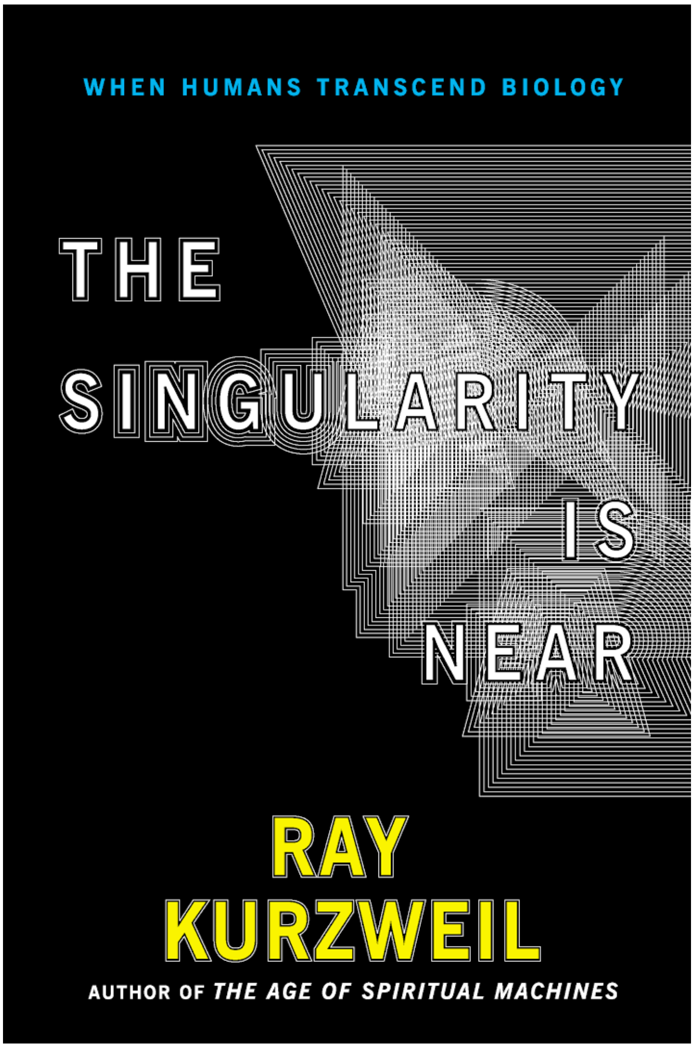




A mathematical singularity: As *x* approaches zero (from right to left), 1/*x* (or *y*) approaches infinity.

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.



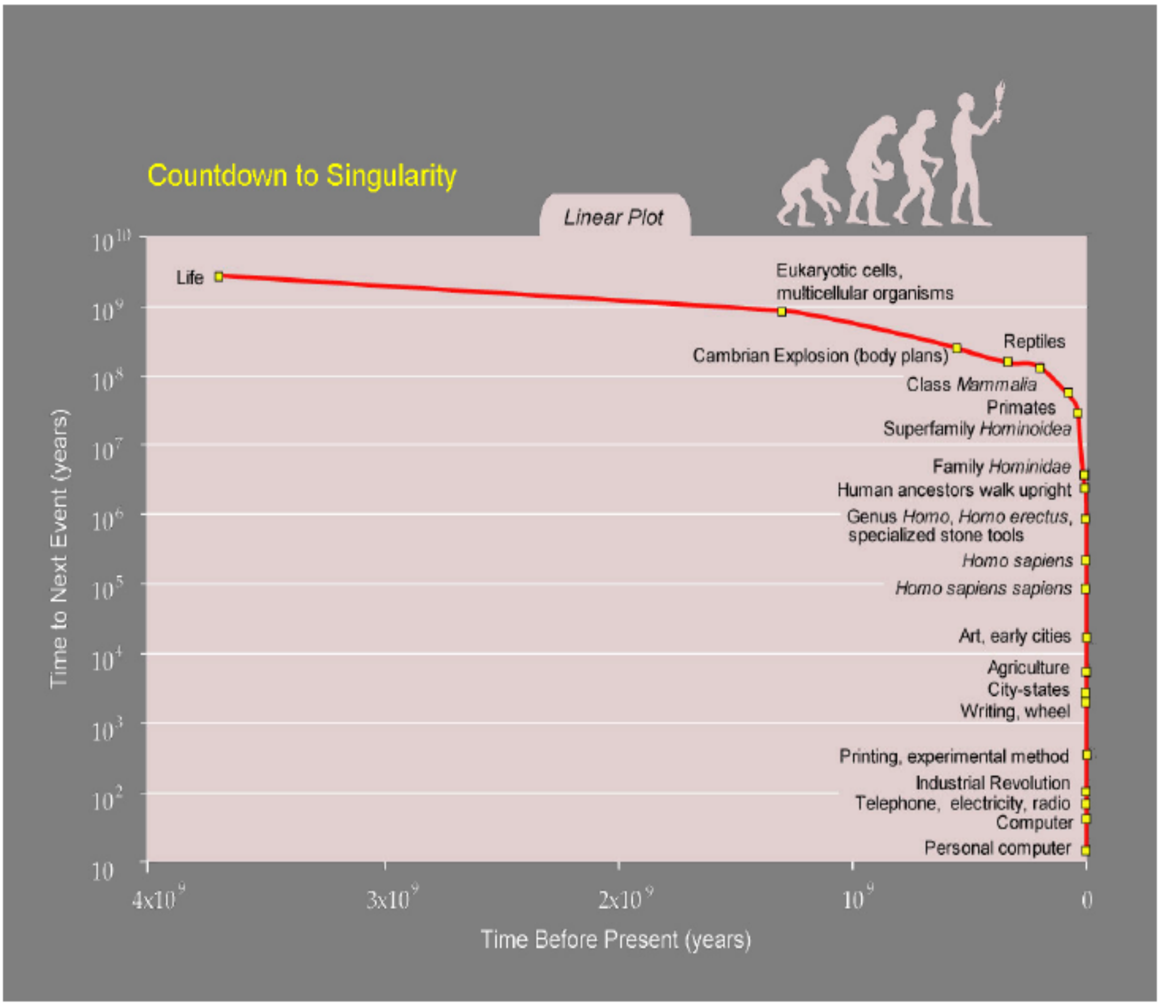


Fig. 1. "Countdown to Singularity" according to Raymond Kurzweil
Source: Kurzweil 2005: 18 (reproduced with permission of Raymond Kurzweil)

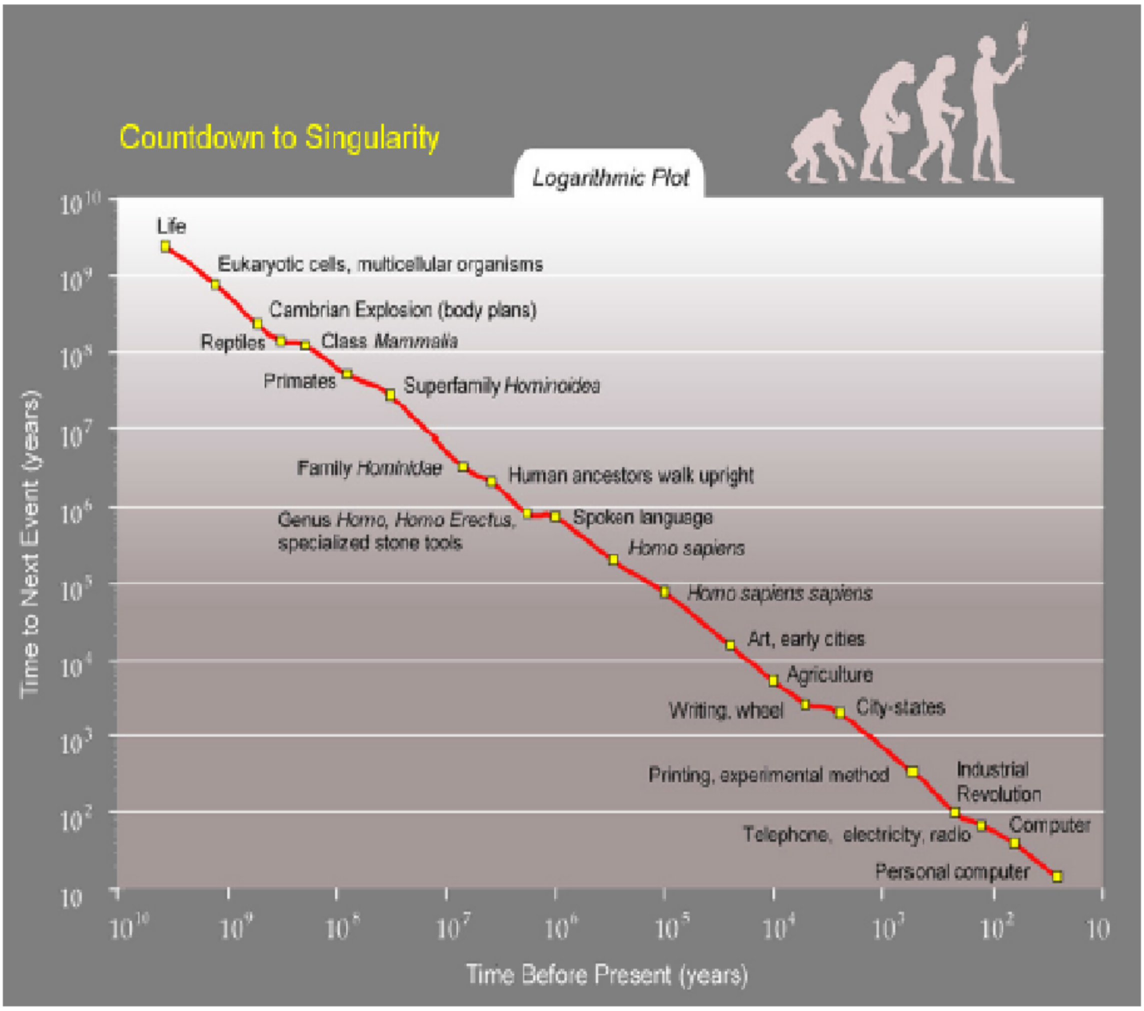


Fig. 2. The first log-log version of Kurzweil's "Countdown to Singularity" graph. *Source*: Kurzweil 2005: 17 (reproduced with permission of Raymond Kurzweil)

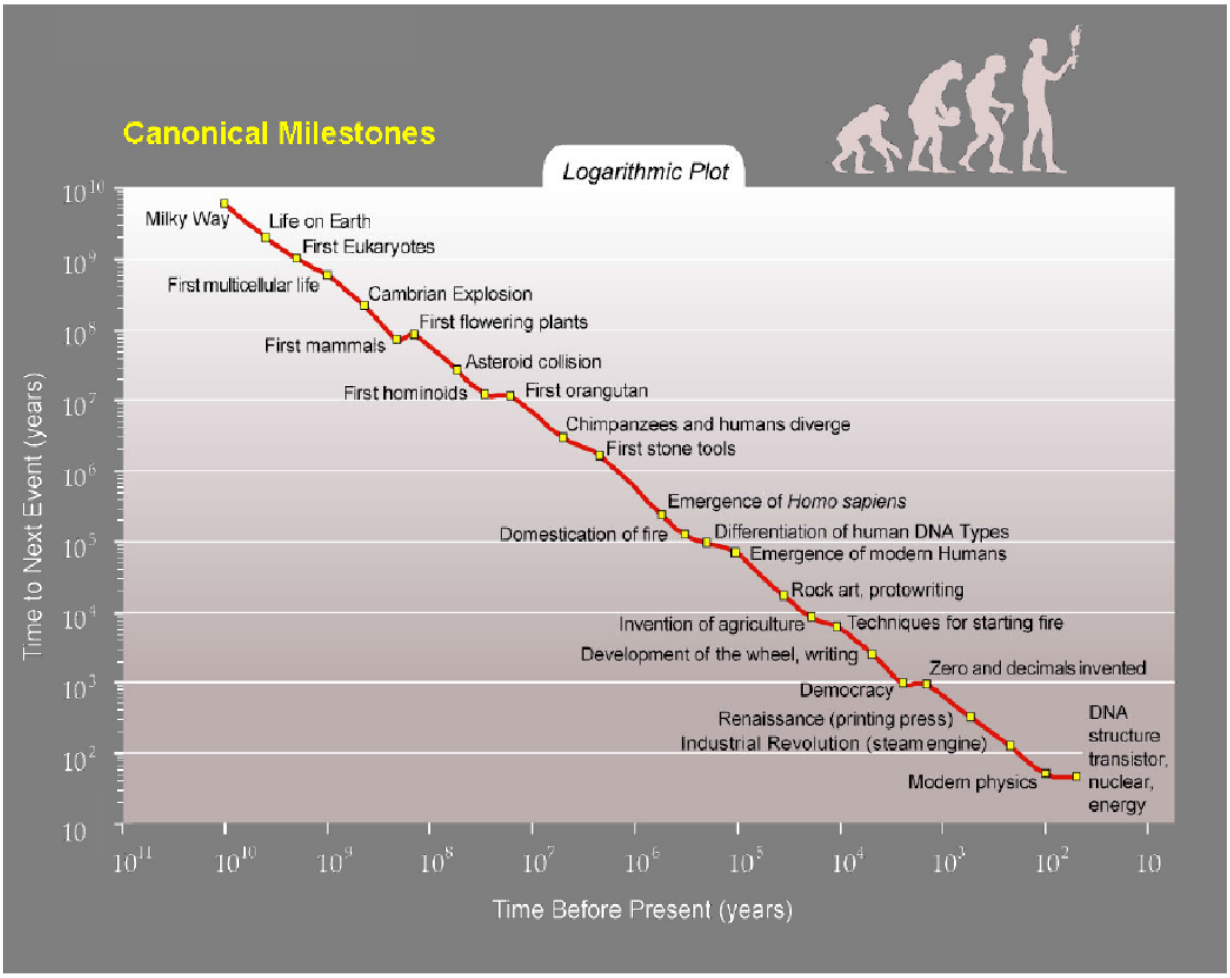


Fig. 3. The second log-log version of Kurzweil's "Countdown to Singularity" graph (= "Canonical Milestones"). *Source*: Kurzweil 2005: 20 (reproduced with permission of Raymond Kurzweil)

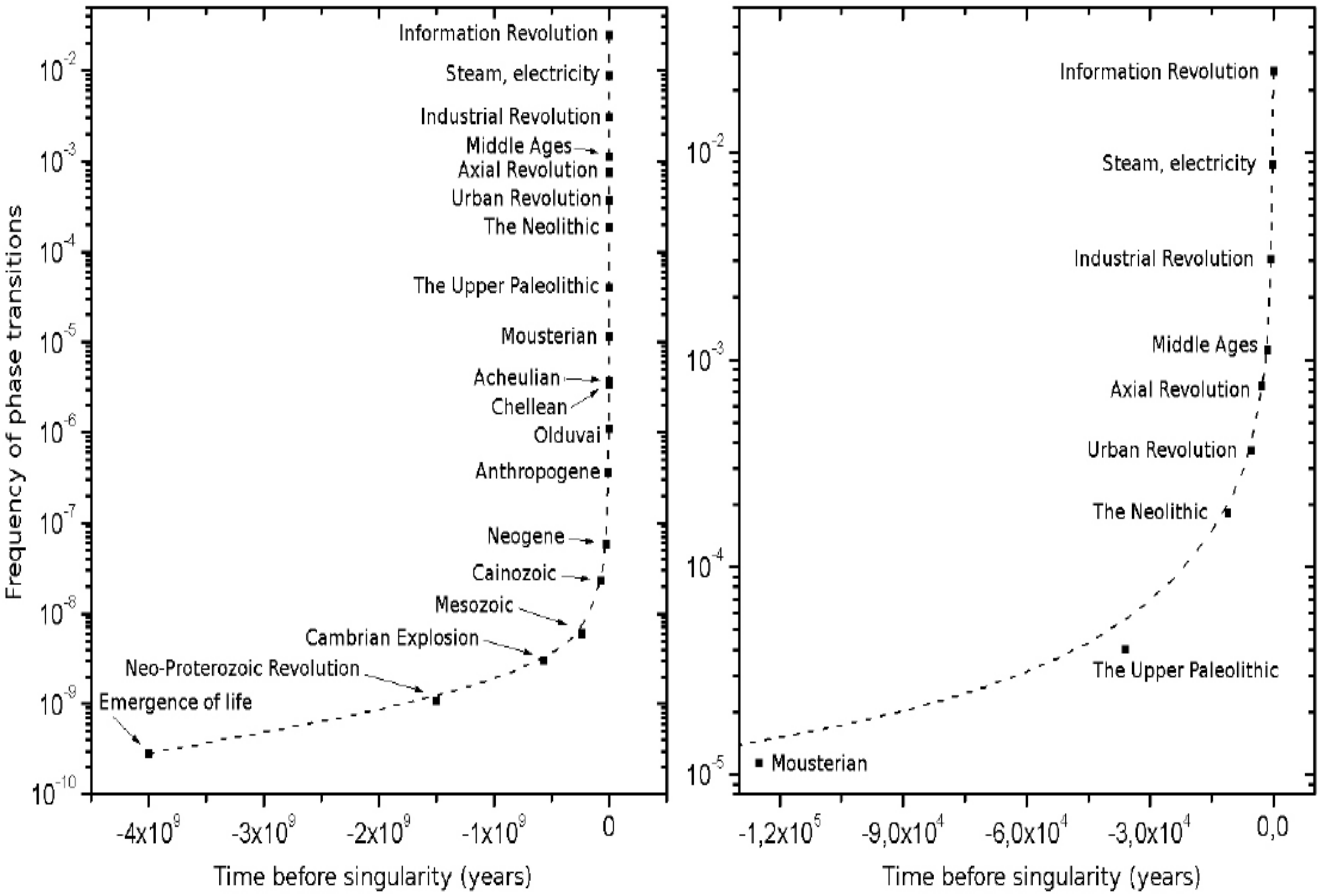


Fig. 4 The dynamics of the global macrodevelopment rate according to Panov (*source*: Nazaretyan 2018: 31, Fig. 3)

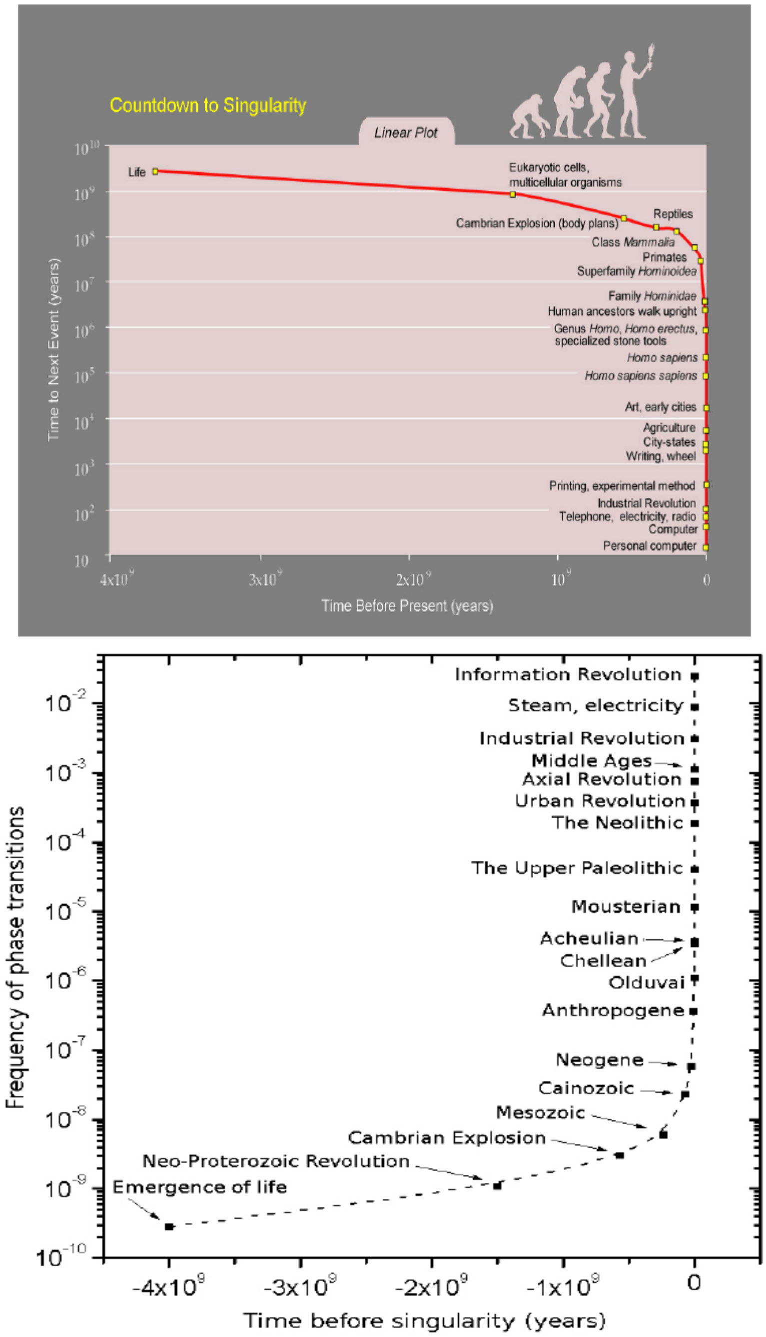


Fig. 5 Comparison between Kurzweil's "Countdown to Singularity" and Panov's graphic depiction of the dynamics of the "frequency of global phase transitions" (= global macroevolution rate)

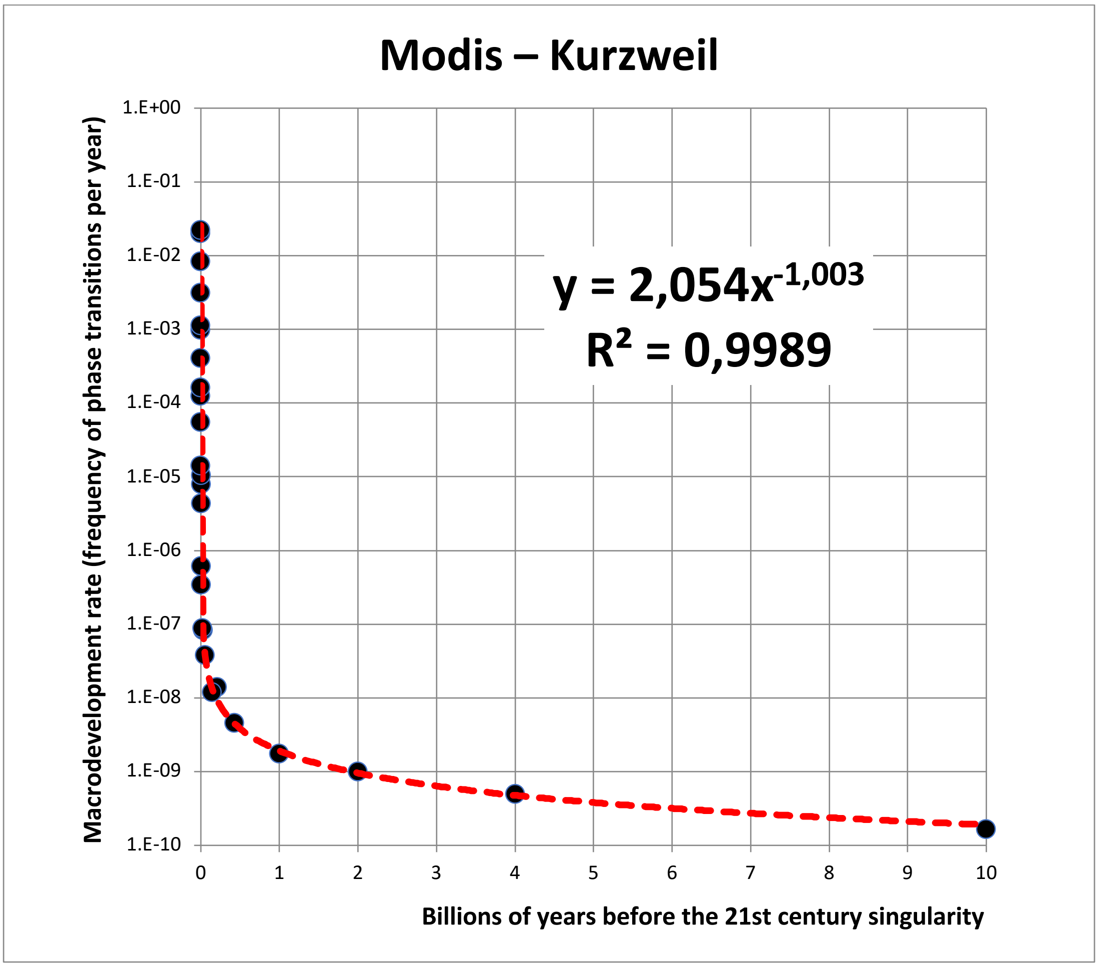


Fig. 6 Scatterplot of the phase transition points from the Modis – Kurzweil list with the fitted power-law regression line (with a **logarithmic scale for the Y-axis**) – **for the Singularity date identified as 2029 CE** with the least squares method

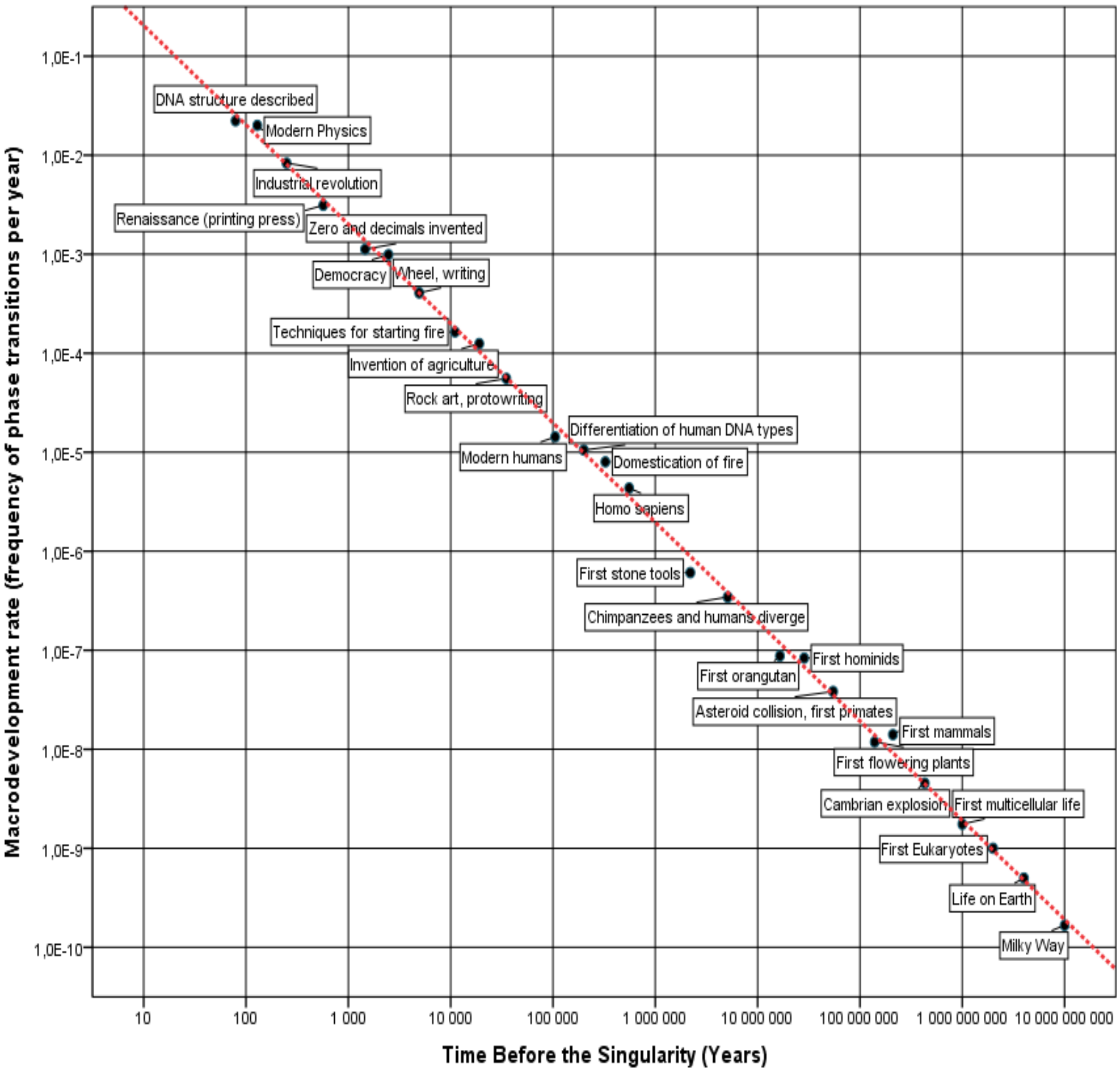
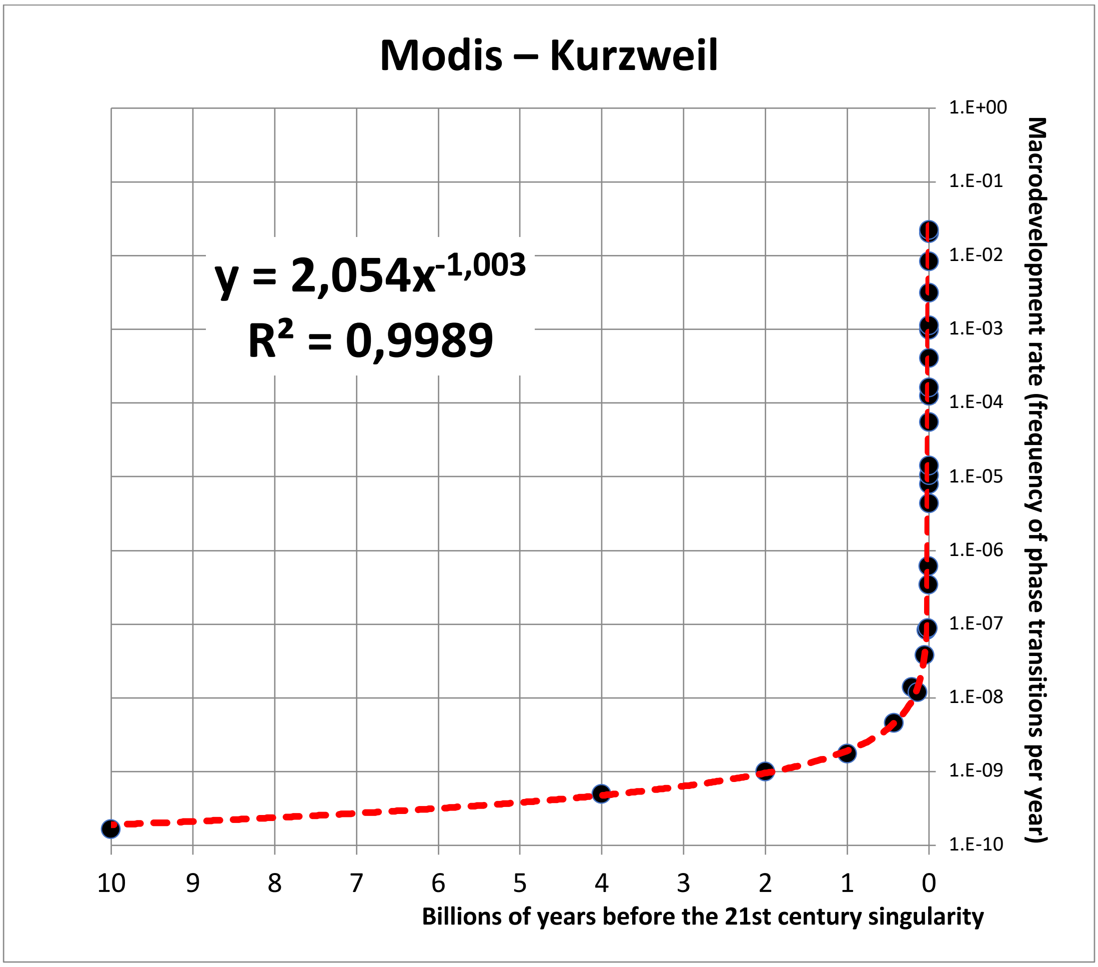
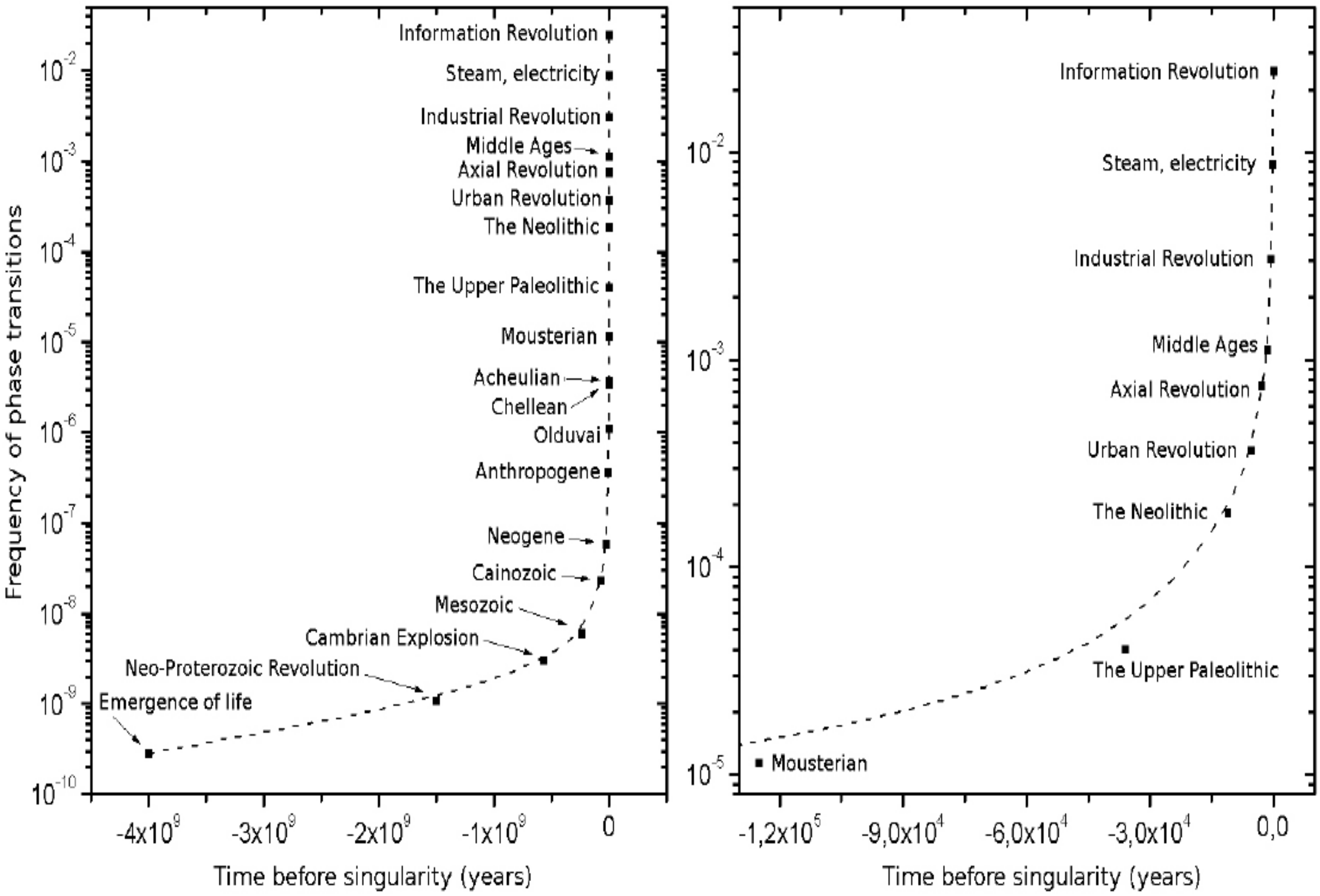


Fig. 7 Scatterplot of the phase transition points from the Modis – Kurzweil list with the fitted power-law regression line (**double logarithmic scale**) – for the Singularity date identified as 2029 CE with the least squares method



Modis – Kurzweil
y = 2,054x-1,003
R² = 0,9989
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
Macrodevelopment rate (frequency of phase transitions per year)
10
9
8
7
6
5
4
3
2
1
0
Billions of years before the 21st century singularity



The dynamics of the global macrodevelopment rate according to Panov (*source*: Nazaretyan 2018: 31, Fig. 3)

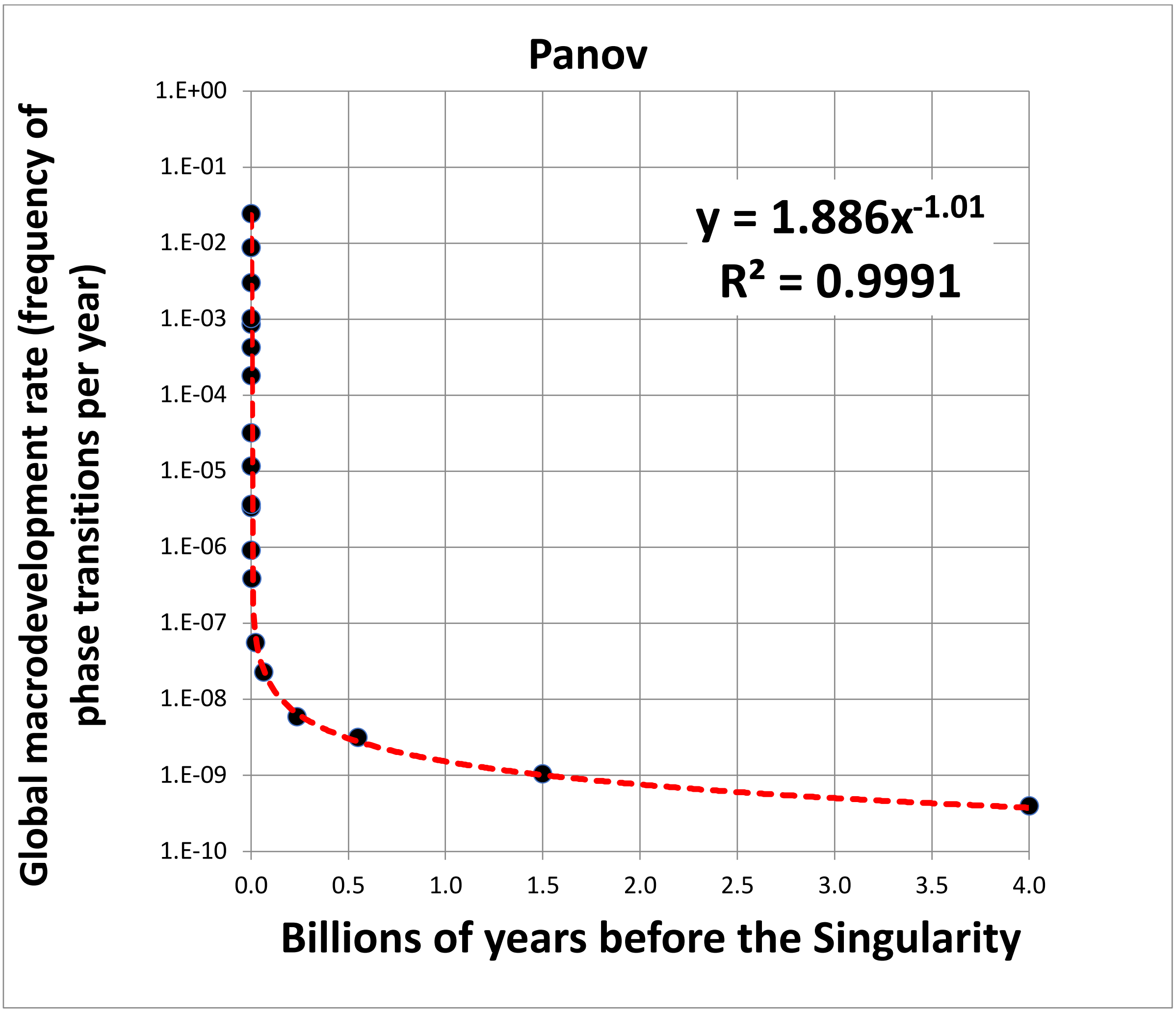


Fig. 8 Scatterplot of the phase transition points from Panov's list with the fitted power-law regression line (with a logarithmic scale for the Y-axis) – **for the Singularity date identified as 2027 CE** with the least squares method

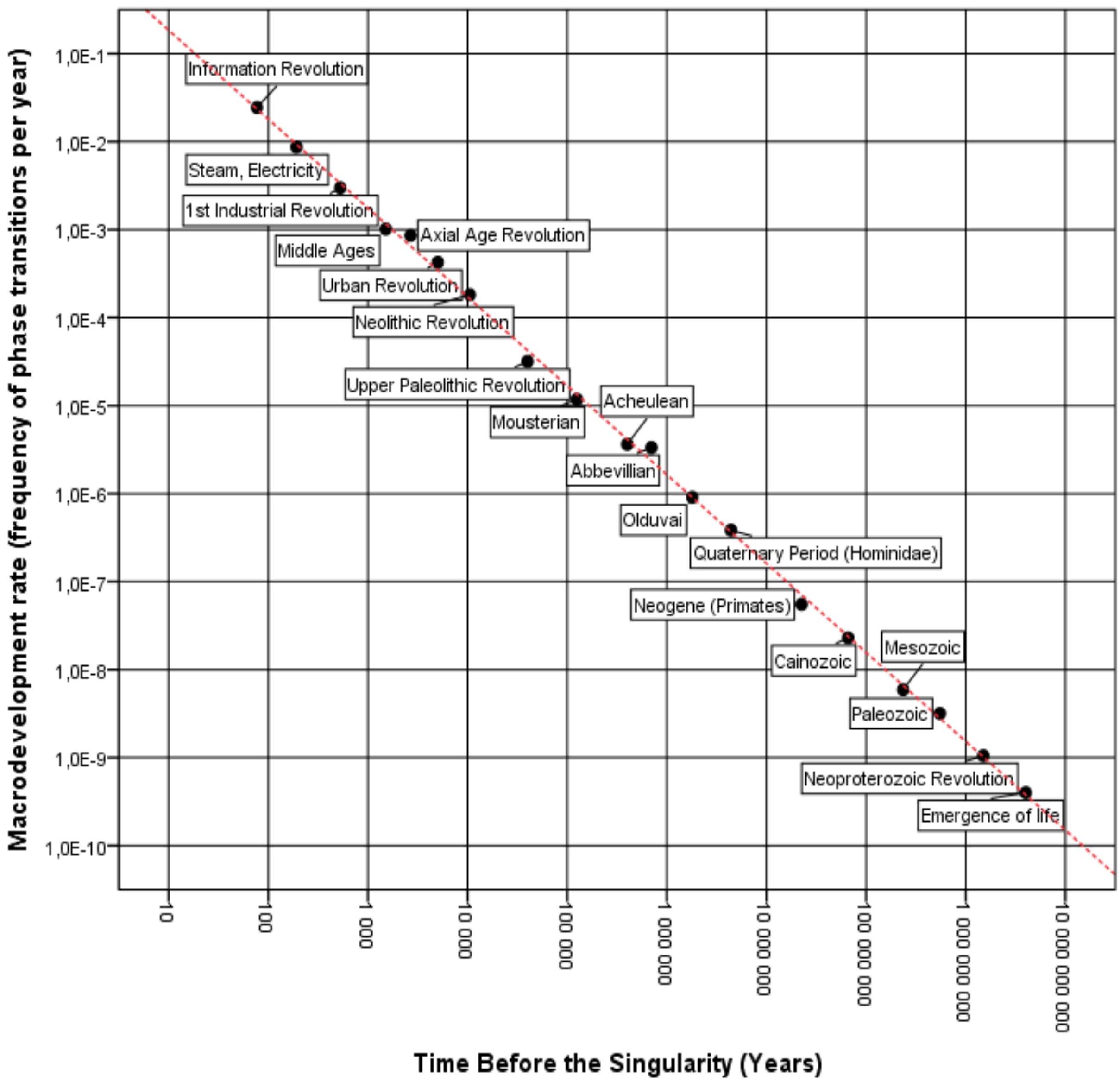
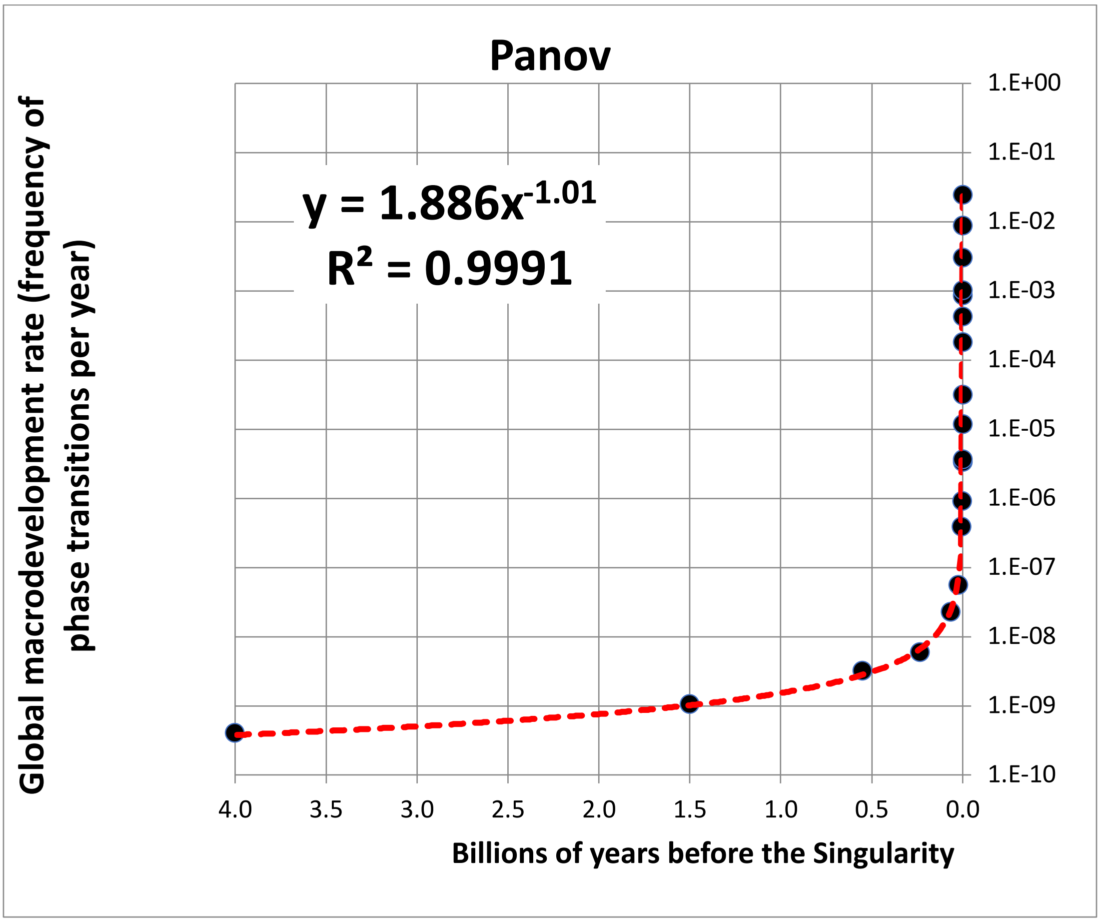


Fig. 9 Scatterplot of the phase transition points from Panov's list with the fitted power-law regression line (double logarithmic scale) – for the Singularity date identified as 2027 CE with the least squares method



Panov
y = 1.886x^-1.01
R² = 0.9991
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
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Billions of years before the Singularity
Global macrodevelopment rate (frequency of phase transitions per year)

$$y = 1.886x^{-1.01}$$
$$R^2 = 0.9991$$

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

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

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

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

Modis – Kurzweil global complexity growth acceleration pattern	**Panov global complexity growth acceleration pattern**
$y = 2.054*x^{-1.003}$ ($R^2 = 0.9989$), where y is the rate of the global (planetary) complexity growth; x is the time till the 21st century Singularity ($t^* = 2029$); $x = t^* - t$; $y = \frac{2.054}{(t^* - t)^{1.003}}$; $y = \frac{2.054}{t^* - t}$; $y = \frac{2.054}{2029 - t}$.	$y = 1.886*x^{-1.01}$ ($R^2 = 0.9991$), where y is the rate of the global (planetary) complexity growth; x is the time till the 21st century Singularity ($t^* = 2027$); $x = t^* - t$; $y = \frac{1.886}{(t^* - t)^{1.01}}$; $y = \frac{1.886}{t^* - t}$; $y = \frac{1.886}{2027 - t}$.

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

Thus, the general formula of the acceleration of the global complexity growth can be described as follows:

- The rate of the global complexity growth increases when we approach the Singularity.
- As the time till the Singularity decreases *n* times, the global complexity growth rate increases the same *n* times.
- Thus, if the time till the Singularity lessens by a factor of 3, the speed of the global complexity growth rises 3 times; if the time till the Singularity diminishes 10 times, the global complexity growth rate escalates by a factor of 10, and so on.

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"

Table 2.4 Comparison between equations describing the planetary complexity growth, on the one hand, and the world population growth, on the other

Equation describing the global complexity growth rate (y) dynamics (for the Panov series)	Equation describing the world population (N) growth (for the von Foerster – Kapitza series)
$y_t = \frac{C_1}{2027 - t}$	$N_t = \frac{C_2}{2027 - t}$

- But how seriously should we take the prediction of “singularity” contained in such mathematical models?
- Should we really expect with Kurzweil that around 2029 we should deal with a few orders of magnitude acceleration of the technological growth (indeed, predicted by one of eguations aboove if we take it literally)?
- I do not think so. This is suggested, for example, by the empirical data on the world population dynamics. As we remember, the global population growth acceleration pattern discovered by Heinz von Foerster is identical with planetary macroevolutionary acceleration patterns of Modis – Kurzweil and Panov, and it is characterized by the singularity parameter (2027 CE) that is simply identical for Panov and has just 2 year difference with Modis – Kurzweil.
- However, what are the grounds to expect that by Friday, November 13, A.D. 2026 the world population growth rate will increase by a few orders of magnitude as is implied by von Foerster equation?
- The answer to this question is very clear. There are no grounds to expect this at all. Indeed, as we showed quite time ago, “von Foerster and his colleagues did not imply that the world population on [November 13, A.D. 2026] could actually become infinite. The real implication was that the world population growth pattern that was followed for many centuries prior to 1960 was about to come to an end and be transformed into a radically different pattern. Note that this prediction began to be fulfilled only in a few years after the "Doomsday" paper was published” (Korotayev 2008: 154).

- Indeed, starting from the early 1970s the world population growth curve began to diverge more and more from the almost ideal hyperbolic shape it had before), and in recent decades it has been taken more and more clearly logistic shape – the trend towards hyperbolic acceleration has been clearly replaced with the logistic slow-down (see Fig. 20):

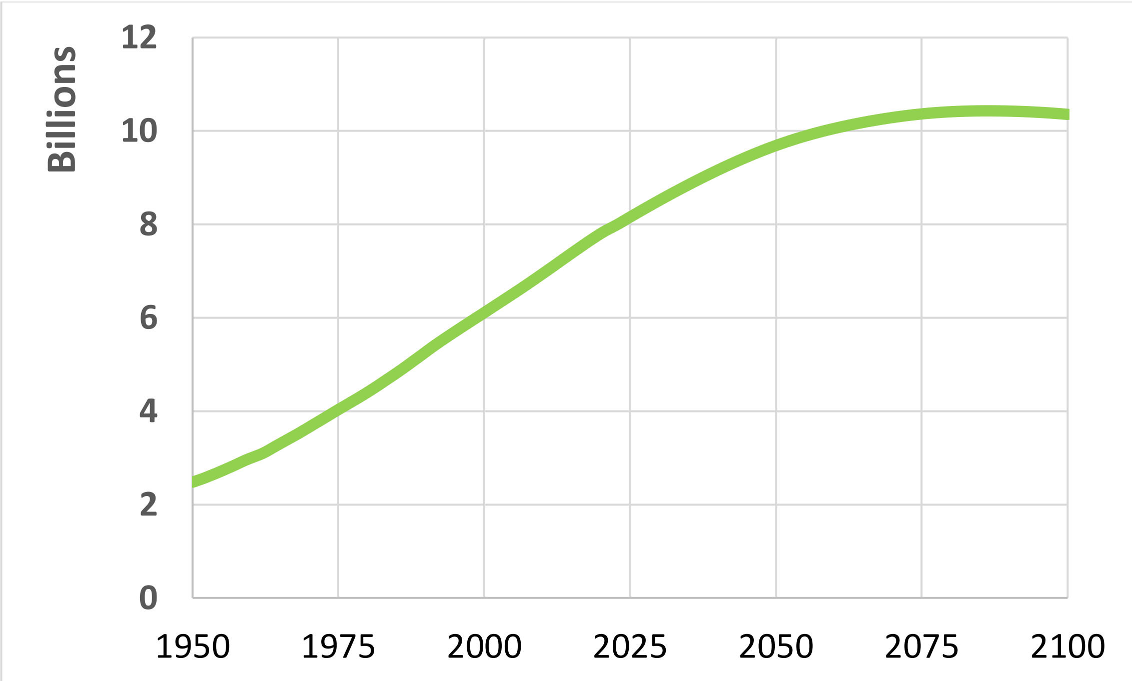


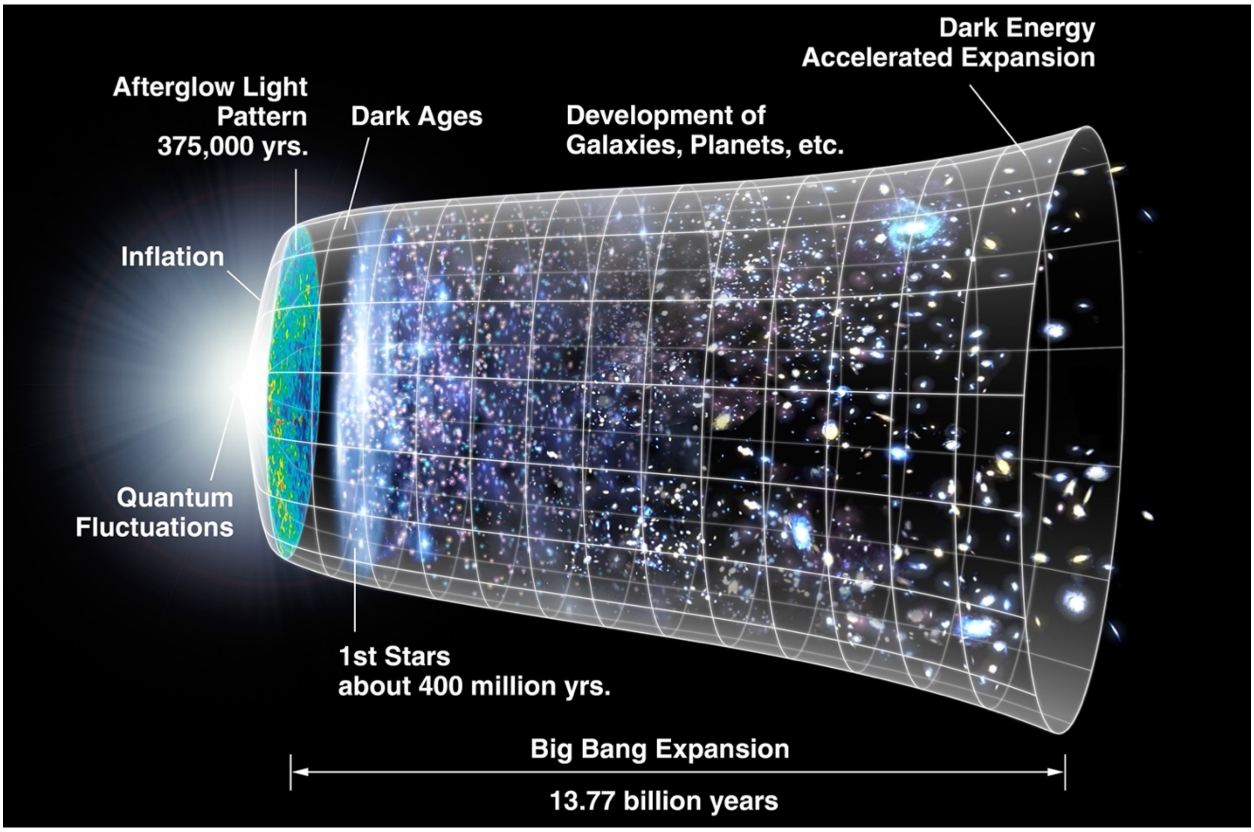
Fig. 10 World population dynamics (billions), empirical estimates of the UN Population Division for 1950–2015 with its middle forecast till 2100. *Data source*: UN Population Division 2022

- There are all grounds to maintain that the deceleration of planetary macroevolutionary development has also already begun – and it started a few decades before the singularity time points detected both in Modis – Kurzweil and Panov.

- Thus, the analysis above appears to indicate the existence of sufficiently rigorous global macroevolutionary regularities (describing the evolution of complexity on our planet for a few billion years), which can be surprisingly accurately described by extremely simple mathematical functions.

- At the same time this analysis suggests that in the region of the singularity point there is no reason, after Kurzweil, to expect an unprecedented (many orders of magnitude) acceleration of the rates of technological development.

- There are more grounds for interpreting this point as an indication of an inflection point, after which the pace of global evolution will begin to slow down systematically in the long term.



Phase transitions and phases of the complexity growth in the Universe (short version)

Phases of the universal complexity growth	***Seconds*** *since the Big Bang Singularity*	***Years*** *since the Big Bang Singularity (~13.8 billion years BP)*
Plank epoch	before 10^{-43}	before $3.17*10^{-51}$
Plank epoch > Grand unification epoch	10^{-43}	$3.17*10^{-51}$
Grand unification epoch	from 10^{-43} to 10^{-36}	from $3.17*10^{-51}$ to $3.17*10^{-44}$
Grand unification epoch > Inflationary epoch	10^{-36}	$3.17*10^{-44}$
Inflationary epoch	from 10^{-36} to 10^{-32}	from $3.17*10^{-44}$ to $3.17*10^{-40}$
Inflationary epoch > Electroweak epoch	10^{-32}	$3.17*10^{-40}$
Electroweak epoch	from 10^{-32} to 10^{-12}	from $3.17*10^{-40}$ to $3.17*10^{-20}$
Electroweak epoch > Quark epoch	10^{-12} (one trillionth of a second)	$3.17*10^{-20}$
Quark epoch	from 10^{-12} to 10^{-5}	from $3.17*10^{-20}$ to $3.17*10^{-13}$
Quark epoch > Hadron epoch	10^{-5} (0.00001, 10 millionths of a second)	$3.17*10^{-13}$

Phases of the universal complexity growth	***Seconds*** *since the Big Bang Singularity*	***Years*** *since the Big Bang Singularity (~13.8 billion years BP)*
Hadron epoch	from 10^{-5} to 1 second since the Big Bang Singularity	from $3.17*10^{-13}$ to $3.17*10^{-8}$
Hadron epoch > Lepton epoch	1 second since the Big Bang Singularity (= after Singularity / AS)	$3.17*10^{-8}$
Lepton epoch, Neutrino decoupling	from 1 to 10 seconds since the Big Bang Singularity / AS	from $3.17*10^{-8}$ to $3.17*10^{-7}$
Lepton epoch > Big Bang nucleosynthesis	10 seconds	$3.17*10^{-7}$
Big Bang nucleosynthesis	from 10 to 1000 seconds AS	from $3.17*10^{-7}$ to $3.17*10^{-5}$
Big Bang nucleosynthesis > Photon epoch	1000 seconds	$3.17*10^{-5}$
Photon epoch	from 1000 seconds	to 18 thousand years AS
Photon epoch > Recombination	$5.68*10^{11}$	$1.8*10^{4}$ (18 thousand years)
Recombination	from $5.68*10^{11}$ to $1.17*10^{13}$	from 18 thousand to 370 thousand years AS
Recombination > Dark ages	$1.17*10^{13}$	370 thousand years since the B. Bang Singularity
Dark ages mid-phase	from $1.17*10^{13}$ to $4.73*10^{15}$	from 370 thousand to 150 million years AS
Dark ages > Population III stars	$4.73*10^{15}$	150 million (13.625 billion years BP)
Population III stars, earliest galaxies, reionization, mid-phase	from $4.73*10^{15}$ to $3.16*10^{16}$	from 150 million to 1 billion years AS
Population III stars > 2nd generation of stars	$3.16*10^{16}$	1 billion (12 billion years BP)
First 3rd generation stars appear against the background of predominance of the 2nd generation of stars, medium complexity galaxies, primitive planets, primitive chemical evolution, mid-phase	from $3.16*10^{16}$ to $2.90*10^{17}$	from 1 billion to 9.2 billion years AS
Predominance of the 2nd population of stars > predominance of the 3rd generation of stars	$2.90*10^{17}$	9.2 billion AS (4.6 billion years BP)
Predominance of the 3rd generation of stars, complex galaxies, complex planets, complex chemical evolution	After $2.90*10^{17}$	After 9.2 billion (after 4.6 billion years BP)

Phase transitions and phases of the complexity growth in the Universe (intermediate version)

Phases of the universal complexity growth	*t – t** **(seconds** since the Big Bang Singularity)	*t – t** **(years** since the Big Bang Singularity)	*Time between phases (years)*	*Universal evolutionary megadevolopment rate (phase transitions per year)*
<u>Plank epoch starts</u>	<u>10^{-47}</u>	<u>$3.17*10^{-55}$</u>		
Plank epoch mid-phase	$5*10^{-44}$	**$1.58*10^{-51}$**	$3.17*10^{-51}$	**$3.16*10^{50}$**
<u>Plank epoch > Grand unification epoch</u>	<u>10^{-43}</u>	<u>$3.17*10^{-51}$</u>		
Grand unification epoch mid-phase	$5*10^{-37}$	**$1.58*10^{-44}$**	$3.17*10^{-44}$	**$3.16*10^{43}$**
<u>Grand unification epoch > Inflationary epoch</u>	<u>10^{-36}</u>	<u>$3.17*10^{-44}$</u>		
Inflationary epoch mid-phase	$5*10^{-33}$	**$1.58*10^{-40}$**	$3.17*10^{-40}$	**$3.16*10^{39}$**
<u>Inflationary epoch > Electroweak epoch</u>	<u>10^{-32}</u>	<u>$3.17*10^{-40}$</u>		
Electroweak epoch mid-phase	$5*10^{-13}$	**$1.58*10^{-20}$**	$3.17*10^{-20}$	**$3.16*10^{19}$**
<u>Electroweak epoch > Quark epoch</u>	<u>10^{-12} (one trillionth of a second)</u>	<u>$3.17*10^{-20}$</u>		
Quark epoch mid-phase	$5*10^{-06}$	**$1.58*10^{-13}$**	$3.17*10^{-13}$ of a year (~1 millionth of a second)	**$3.16*10^{12}$ (3.16 trillion phase transitions per year)**
<u>Quark epoch > Hadron epoch</u>	<u>10^{-05} (0.00001, 10 millionths of a second)</u>	<u>$3.17*10^{-13}$</u>		
Hadron epoch mid-phase	0.500005	**$1.58*10^{-8}$**	$3.17*10^{-8}$ of a year (~1 second)	**$3.16*10^{7}$ (31.6 million phase transitions per year)**
<u>Hadron epoch > Lepton epoch</u>	<u>1 second since the Big Bang Singularity</u>	<u>$3.17*10^{-8}$</u>		
Lepton epoch, Neutrino decoupling, mid-phase	5.5 seconds	**$1.74*10^{-7}$**	$2.87*10^{-7}$ of a year (~9 seconds)	**$3.51*10^{6}$ (3.51 million phase transitions per year)**
<u>Lepton epoch > Big Bang nucleosynthesis</u>	<u>10 seconds</u>	<u>$3.17*10^{-7}$</u>		

Phases of the universal complexity growth	*t – t** (**seconds** since the Big Bang Singularity)	*t – t** (**years** since the Big Bang Singularity)	*Time between phases (years)*	*Universal evolutionary megadevolopment rate (phase transitions per year)*
Big Bang nucleosynthesis mid-phase	505 seconds	**$1.60*10^{-5}$**	$3.14*10^{-5}$	**$3.19*10^{4}$ (31,900 phase transitions per year)**
Big Bang nucleosynthesis > Photon epoch	1000 seconds	$3.17*10^{-5}$		
Photon epoch mid-phase	$2.84*10^{11}$	**$9.0*10^{3}$ (9 thousand years since the B. Bang Singularity)**	$1.8*10^{4}$ (18 thousand years)	**$5.56*10^{-5}$ (5.56 phase transitions per 100 thousand years)**
Photon epoch > Recombination	$5.68*10^{11}$	$1.8*10^{4}$ (18 thousand years)		
Recombination mid-phase	$6.12*10^{12}$	**194 thousand years AS**	$3.52*10^{5}$ (352 thousand years)	**$2.84*10^{-6}$ (2.28 phase transitions per 1 million years)**
Recombination > Dark ages	$1.17*10^{13}$	370 thousand years since the B. Bang Singularity		
Dark ages mid-phase	$2.37*10^{15}$	**75.2 million (13.7 billion years BP)**	$1.496*10^{8}$ (149.63 million years)	**$6.68*10^{-9}$ (6.68 phase transitions per 1 billion years)**
Dark ages > Population III stars	$4.73*10^{15}$	150 million (13.625 billion years BP)		
Population III stars, earliest galaxies, reionization, mid-phase	$1.81*10^{16}$	**575 million (13.2 billion years BP)**	$8.5*10^{8}$ (850 million years)	**$1.18*10^{-9}$ (1.18 phase transitions per 1 billion years)**
Population III stars > 2nd generation of stars	$3.16*10^{16}$	1 billion (12 billion years BP)		
First 3rd generation stars appear against the background of predominance of the 2nd generation of stars, medium complexity galaxies, primitive planets, primitive chemical evolution, mid-phase	$1.61*10^{17}$	**5.1 billion (8,7 billion years BP)**	8.20E+09 $8.2*10^{9}$ (8.2 billion years)	**$1.22*10^{-10}$ (1.22 phase transitions per 10 billion years)**

Phases of the universal complexity growth	*t – t** (**seconds** since the Big Bang Singularity)	*t – t** (**years** since the Big Bang Singularity)	*Time between phases (years)*	*Universal evolutionary megadevolopment rate (phase transitions per year)*
Predominance of the 2nd population of stars > predominance of the 3rd generation of stars	$2.90*10^{17}$	9.2 billion (4.6 billion years BP)		
Predominance of the 3rd generation of stars, complex galaxies, complex planets, complex chemical evolution	After $2.90*10^{17}$	After 9.2 billion years AS (after 4.6 billion years BP)	?	?

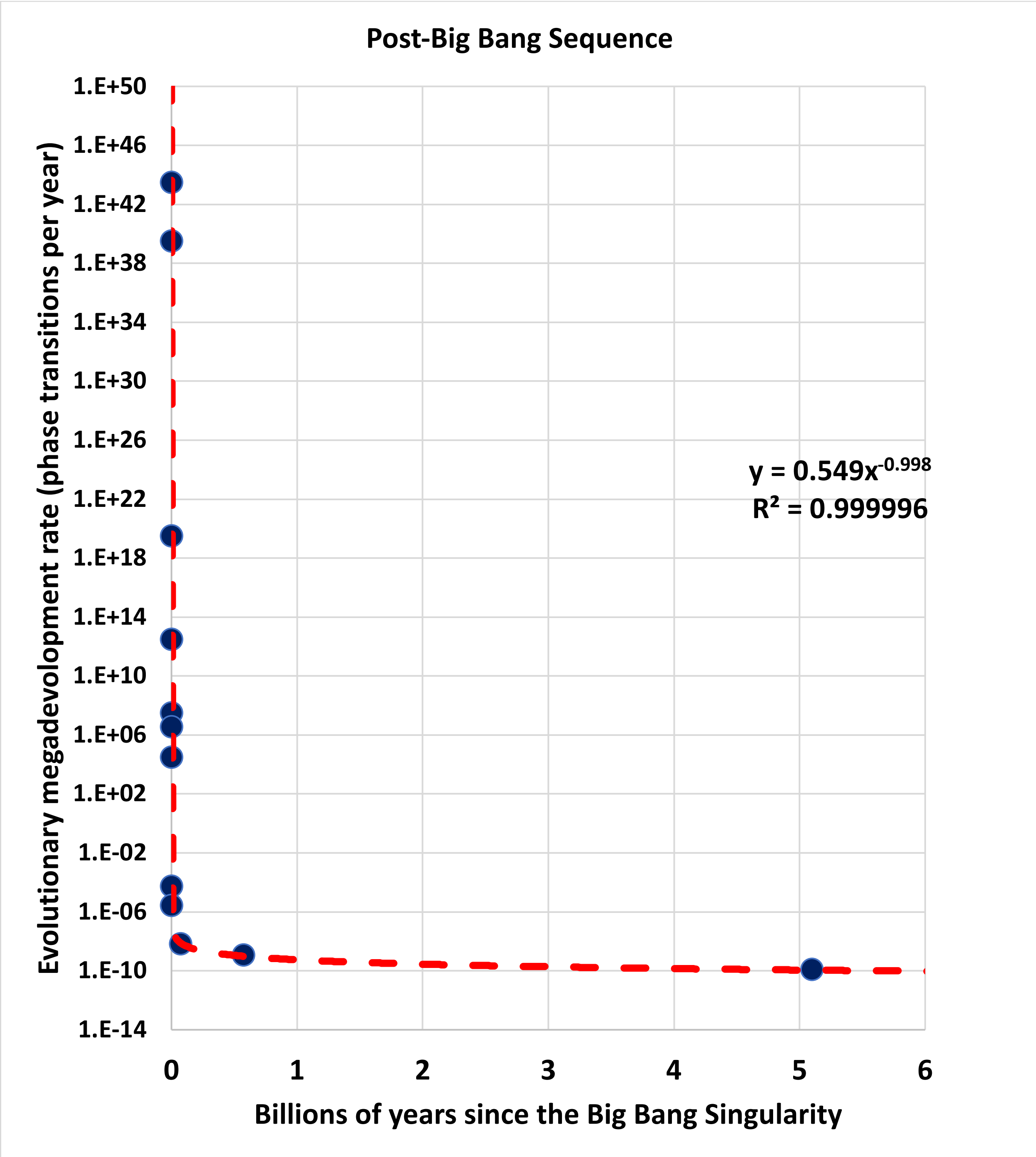


Fig. 11 Correlation between the time since the Big Bang Singularity and evolutionary megadevolopment rate (phase transitions per year). Scatterplot of the phases of the growth of complexity in the Universe, with the fitted power-law regression line **(with a logarithmic scale for the Y-axis)**

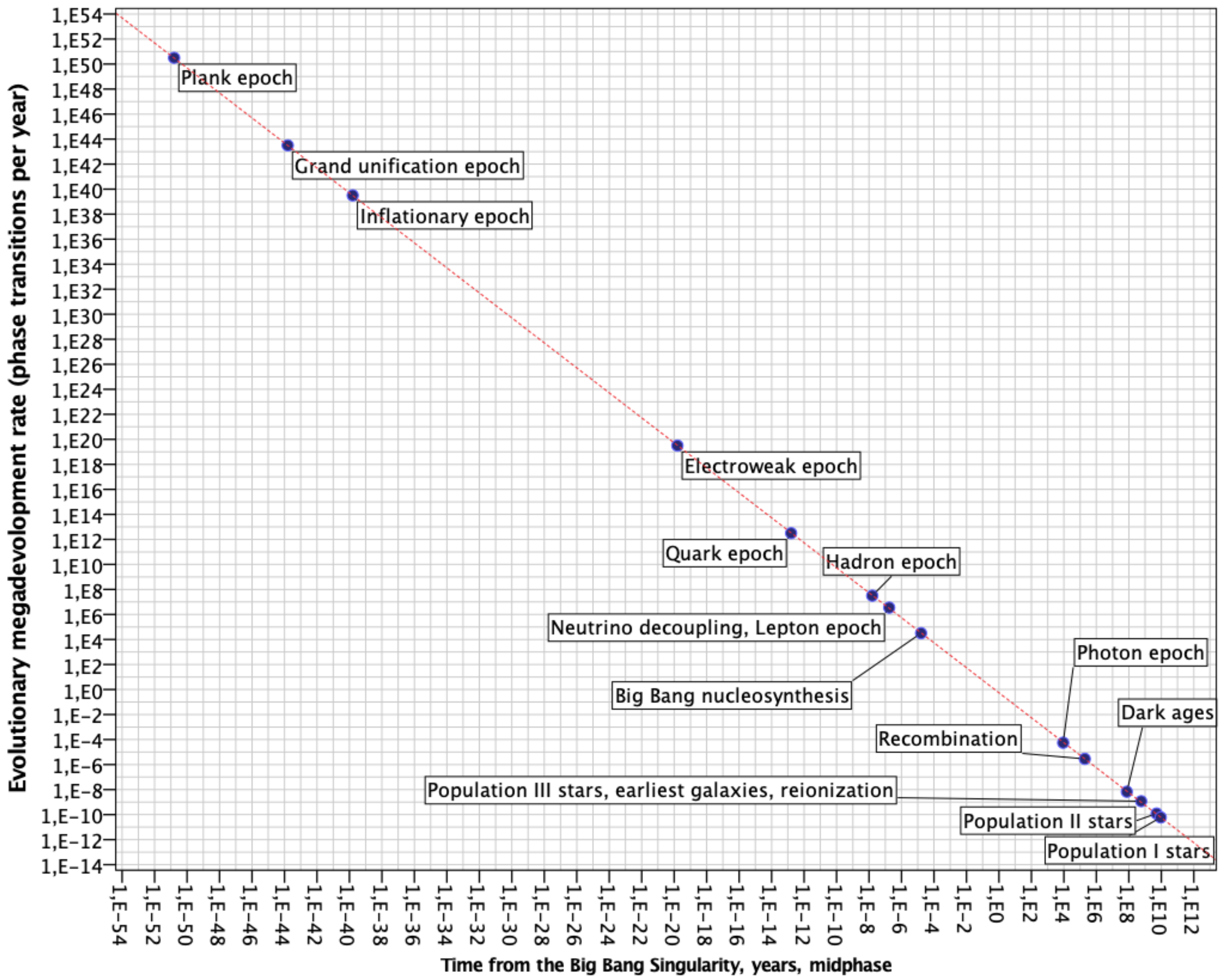


Fig. 12 Correlation between the time since the Big Bang Singularity and evolutionary megadevolopment rate (phase transitions per year). Scatterplot of the phases of the growth of complexity in the Universe, with the fitted power-law regression line **(log-log scale)**

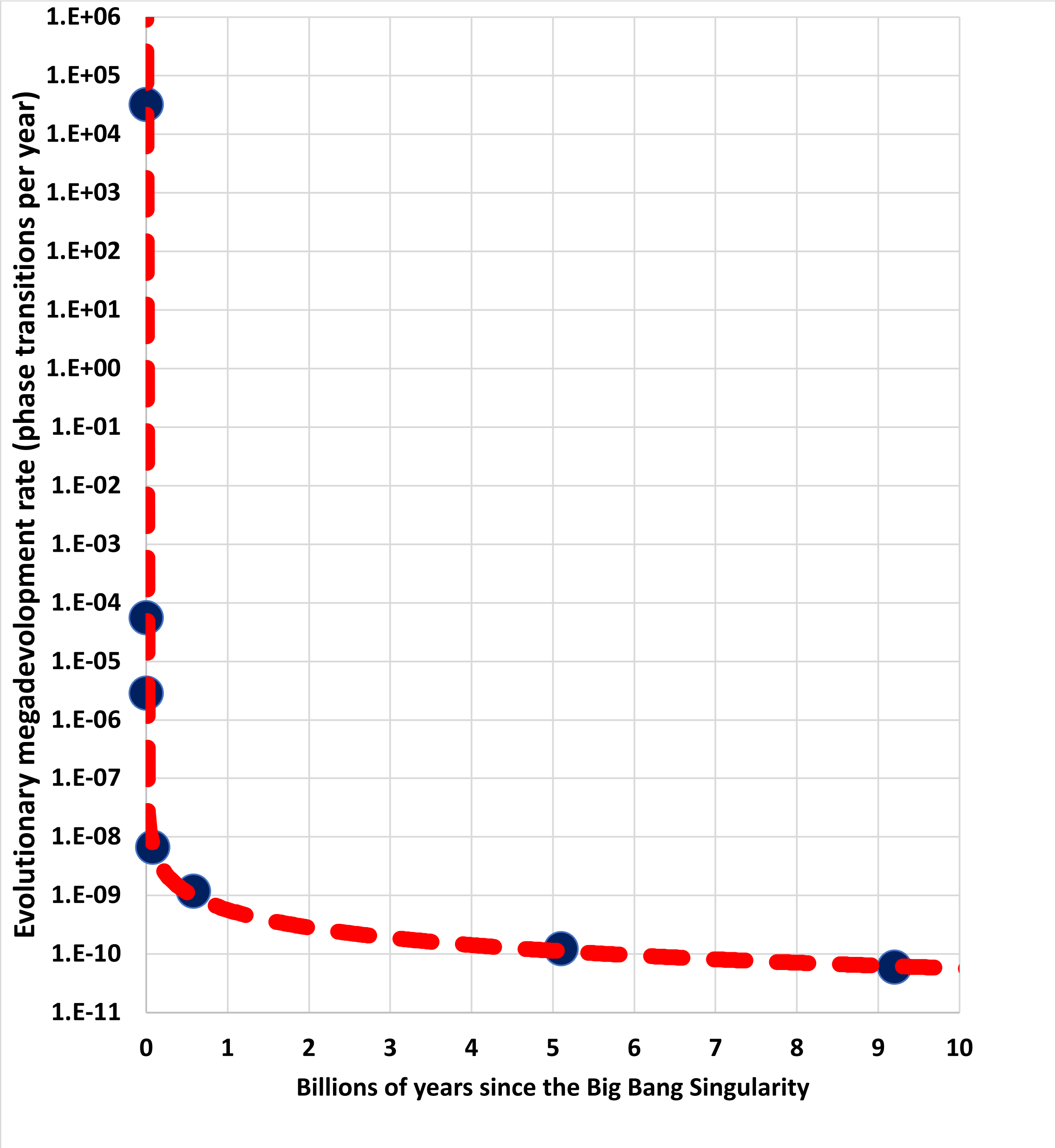


Fig. 13 Correlation between the time since the Big Bang Singularity and evolutionary megadevolopment rate (phase transitions per year). Scatterplot of the phases of the growth of complexity in the Universe, the fitted power-law regression line (with a logarithmic scale for the Y-axis), **for the period since 1 second after the Big Bang Singularity**

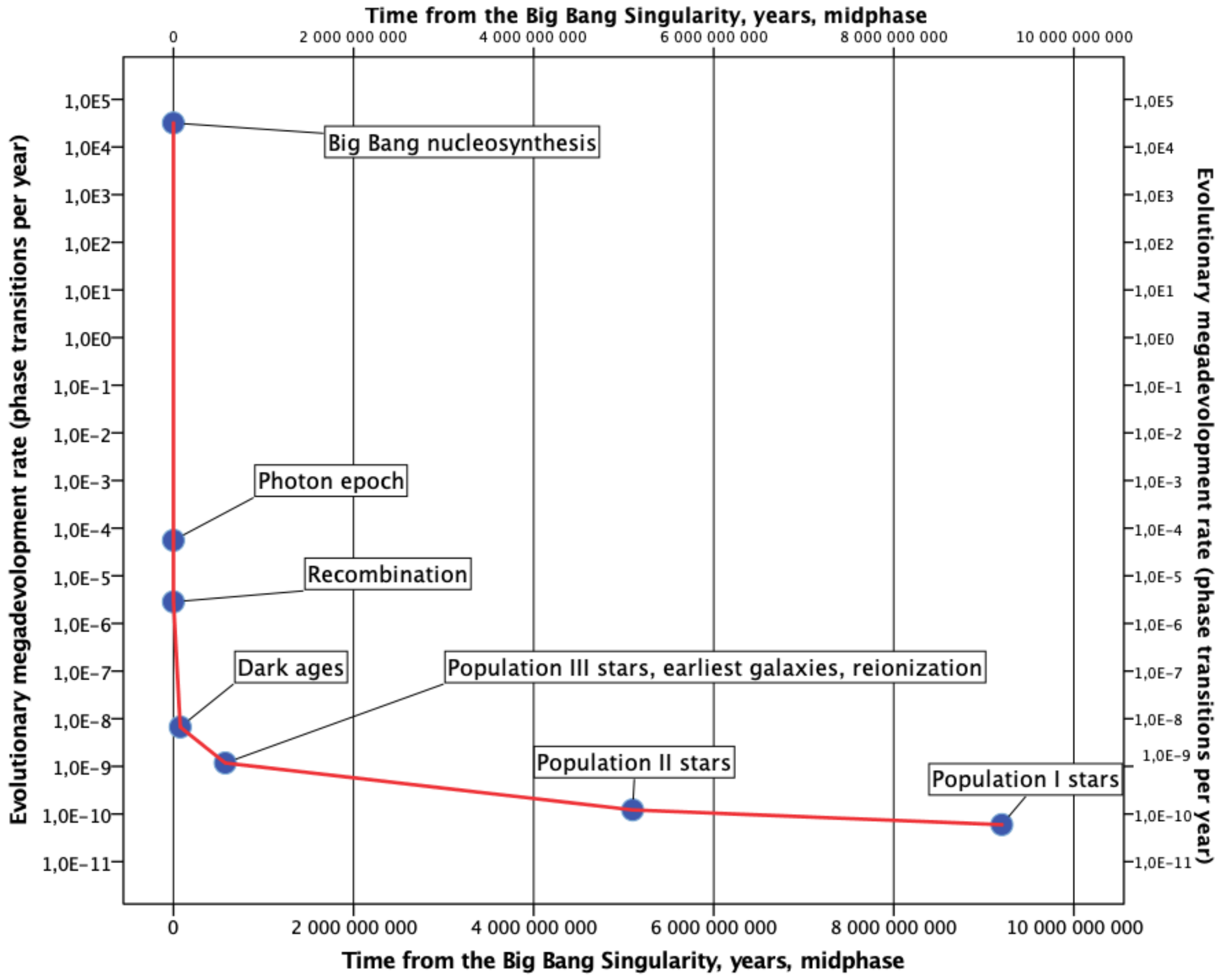


Fig. 14 Phases of the growth of complexity in the Universe **since 1 second after the Big Bang Singularity.** Correlation between the time since the Big Bang Singularity and evolutionary megadevolopment rate (phase transitions per year)

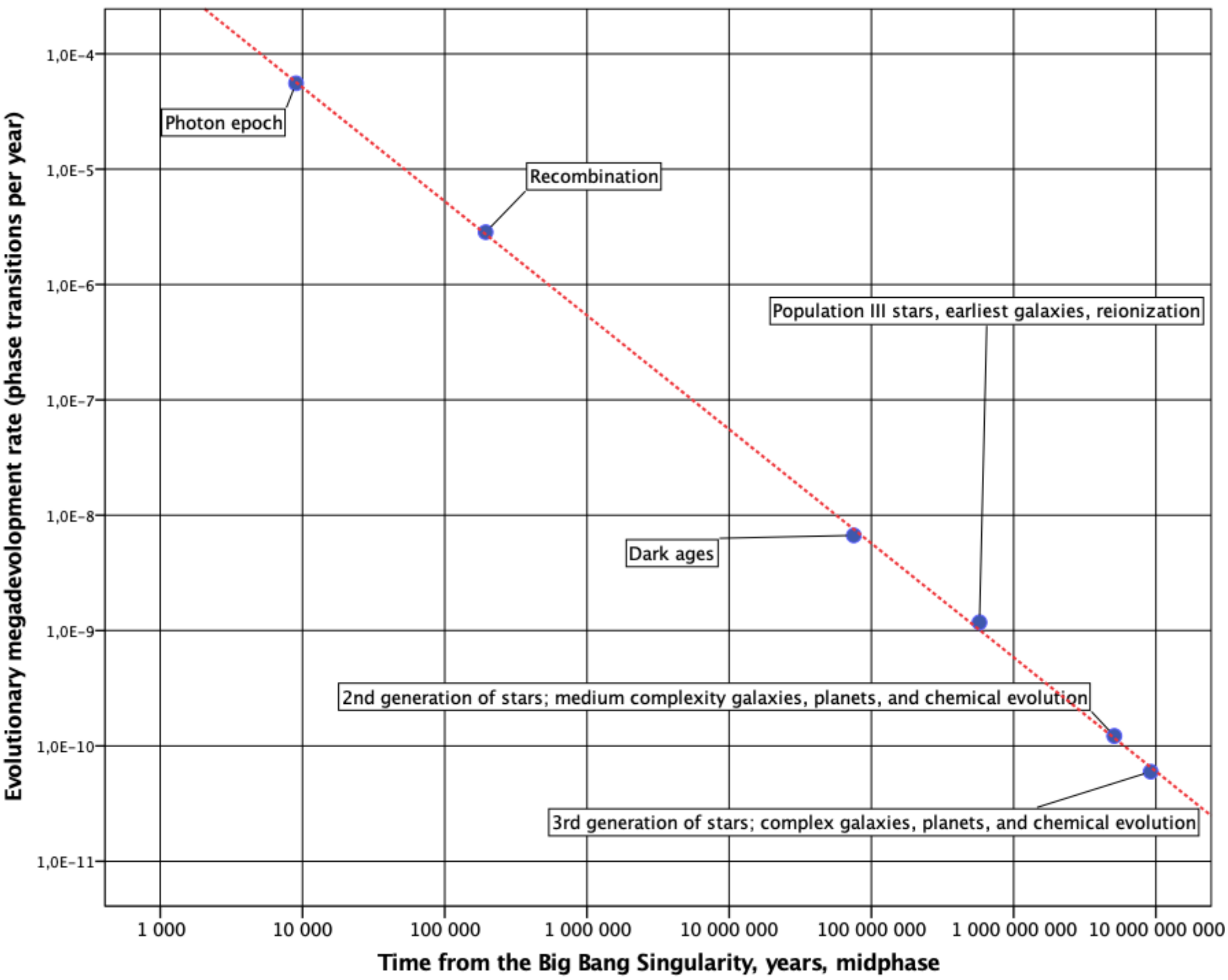
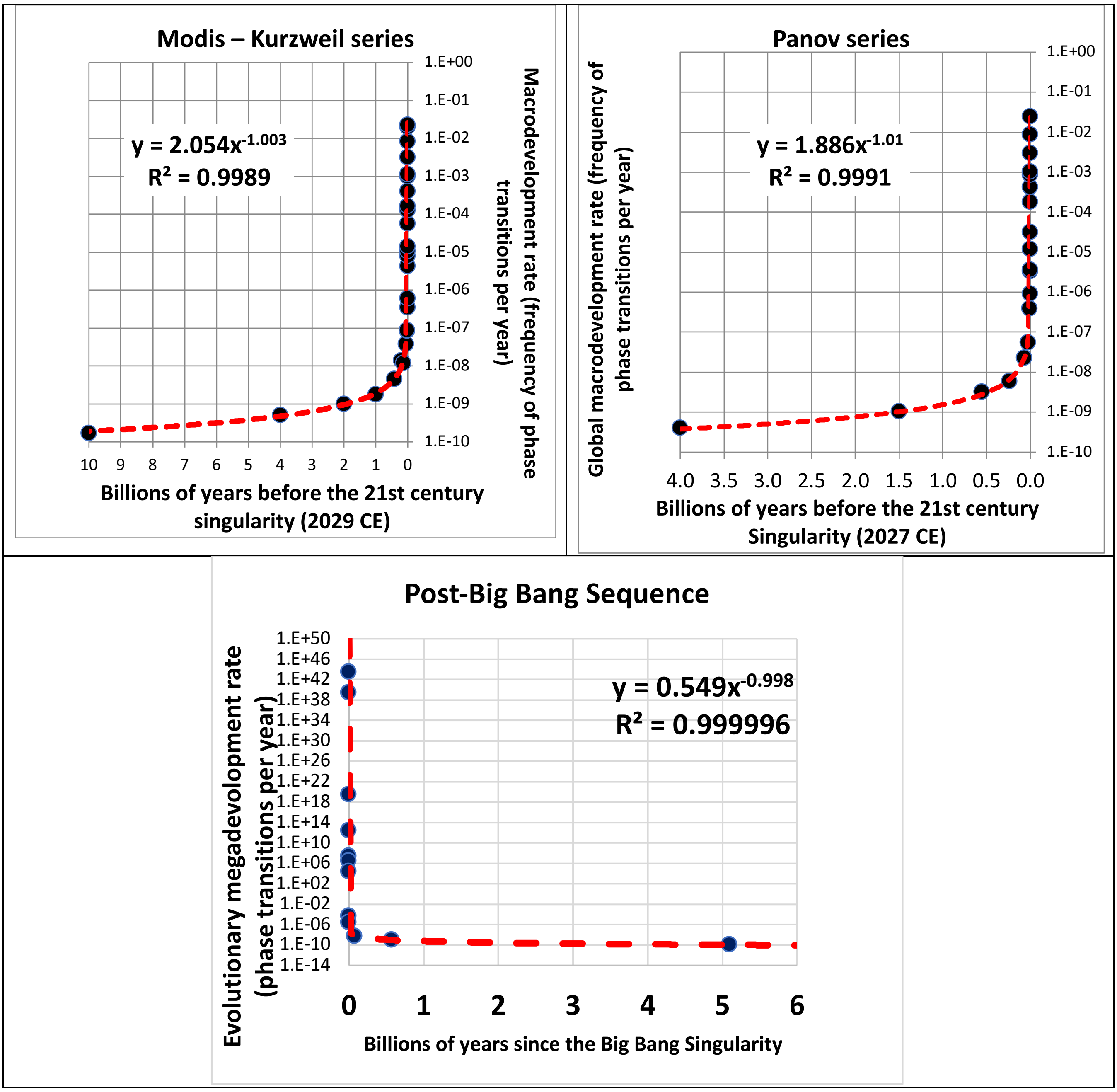


Fig. 15 Phases of the growth of complexity in the Universe **since 1000 years after the Big Bang Singularity.** Correlation between the time since the Big Bang Singularity and evolutionary megadevolopment rate (phase transitions per year), **(log-log scale)**

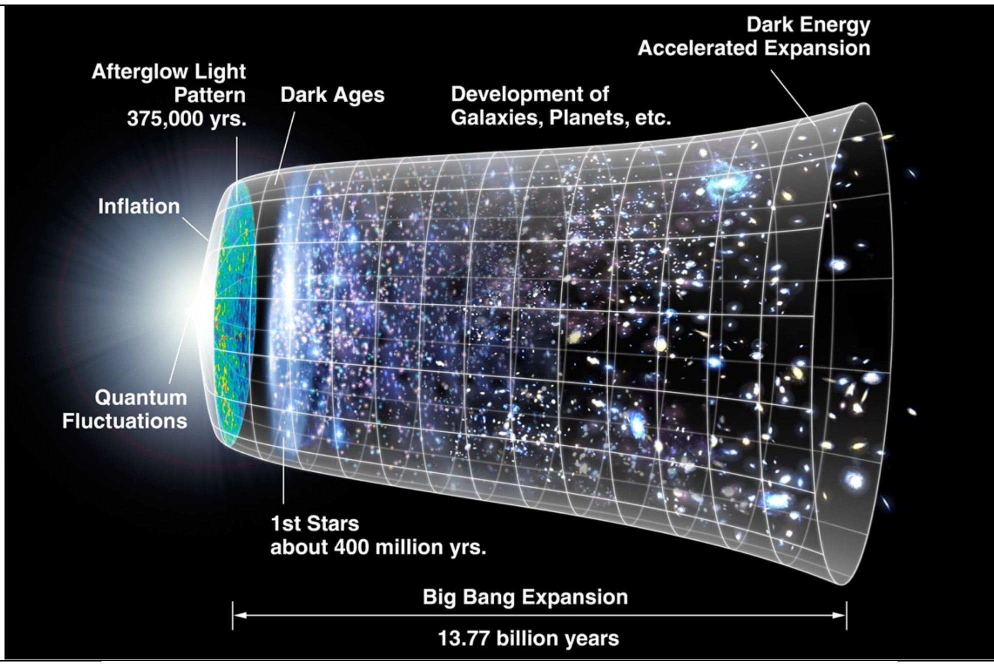


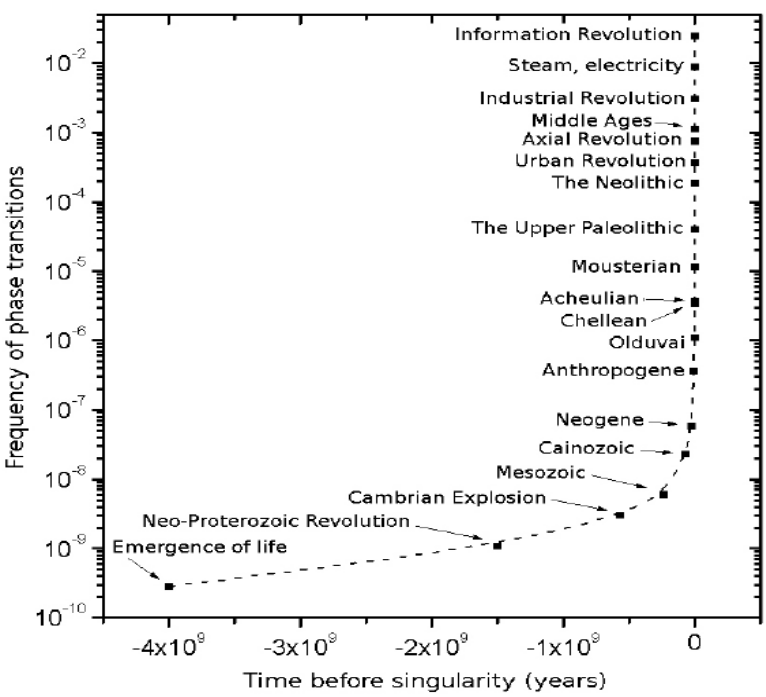
Modis – Kurzweil series
y = 2.054x-1.003
R² = 0.9989
1.E+00
1.E-01
1.E-02
1.E-03
1.E-04
1.E-05
1.E-06
1.E-07
1.E-08
1.E-09
1.E-10
10 9 8 7 6 5 4 3 2 1 0
Billions of years before the 21st century singularity (2029 CE)
Macrodevelopment rate (frequency of phase transitions per year)
Panov series
y = 1.886x-1.01
R² = 0.9991
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
4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
Billions of years before the 21st century Singularity (2027 CE)
Global macrodevelopment rate (frequency of phase transitions per year)
Post-Big Bang Sequence
y = 0.549x-0.998
R² = 0.999996
1.E+50
1.E+46
1.E+42
1.E+38
1.E+34
1.E+30
1.E+26
1.E+22
1.E+18
1.E+14
1.E+10
1.E+06
1.E+02
1.E-02
1.E-06
1.E-10
1.E-14
0 1 2 3 4 5 6
Billions of years since the Big Bang Singularity
Evolutionary megadevolopment rate (phase transitions per year)

<table>
<tr><th>Modis – Kurzweil global complexity growth acceleration pattern</th><th>Panov global complexity growth acceleration pattern</th></tr>
<tr><td>$y = 2.054*x^{-1.003}$ ($R^2 = 0.9989$),
where y is the rate of the global (planetary) complexity growth;
x is the time till the 21st century Singularity ($t^* = 2029$); $x = t^* - t$;
$y = \frac{2.054}{(t^* - t)^{1.003}}$;
$y = \frac{2.054}{t^* - t}$; $\boldsymbol{y = \frac{C_1}{t^* - t}}$
$y = \frac{2.054}{2029 - t}$.</td><td>$y = 1.886*x^{-1.01}$ ($R^2 = 0.9991$),
where y is the rate of the global (planetary) complexity growth;
x is the time till the 21st century Singularity ($t^* = 2027$); $x = t^* - t$;
$y = \frac{1.886}{(t^* - t)^{1.01}}$;
$y = \frac{1.886}{t^* - t}$; $\boldsymbol{y = \frac{C_1}{t^* - t}}$
$y = \frac{1.886}{2027 - t}$.</td></tr>
<tr><td colspan="2">Universal complexity growth deceleration pattern</td></tr>
<tr><td colspan="2">$y = 0.549*x^{-0.998}$ ($R^2 = 0.999996$),
where y is the rate of the universal complexity growth;
x is the time since the Big Bang Singularity ($t^* = 13.8$ biillion BP); $x = t - t^*$;
$y = \frac{0.549}{(t - t^*)^{0.998}}$;
$y = \frac{0.549}{t - t^*}$; $\boldsymbol{y = \frac{C_2}{t - t^*}}$
$y = \frac{0.549}{t - 13.8 \cdot 10^9 \text{BCE}}$.</td></tr>
</table>

Decelerating universal (cosmic) evolutionary development	Accelerating global (biosocial) evolutionary development
$y = \dfrac{0.55}{t - t^*}$	$y = \dfrac{1.89}{t^* - t}$
$y = \dfrac{C_1}{t - t^*}$	$y = \dfrac{C_2}{t^* - t}$
Thus, the general formula of the deceleration of the universal (cosmic) complexity growth can be described as follows: • The rate of the universal (cosmic) complexity growth decreases when we move from the Singularity. • As the time since the Singularity increases *n* times, the universal (cosmic) complexity growth rate decreases the same *n* times. • Thus, if the time till the Singularity rises by a factor of 3, the speed of the universal (cosmic) complexity growth lessens 3 times; if the time till the Singularity increases 10 times, the universal (cosmic) complexity growth rate diminishes by a factor of 10, and so on.	Thus, the general formula of the acceleration of the global (biosocial) complexity growth can be described as follows: • The rate of the global complexity growth increases when we approach the Singularity. • As the time till the Singularity decreases *n* times, the global complexity growth rate increases the same *n* times. • Thus, if the time till the Singularity lessens by a factor of 3, the speed of the global complexity growth rises 3 times; if the time till the Singularity diminishes 10 times, the global complexity growth rate escalates by a factor of 10, and so on.

Desynchronization





Phase transitions and phases of the complexity growth in the Universe (advanced version)

Phases of the universal complexity growth	$t - t^*$ (**seconds** since the Big Bang Singularity)	$t - t^*$ (**years** since the Big Bang Singularity)	*Time between phases (years)*	*Universal evolutionary megade-volopment rate (phase transitions per year)*	Radiation temperature (energy) of the Universe, in electronvolts (eV)	Radiation temperature (energy) of the Universe, in Kelvins (K)
Plank epoch starts	10^{-47}	$3.17*10^{-55}$				
Plank epoch mid-phase	$5*10^{-44}$	**$1.58*10^{-51}$**	$3.17*10^{-51}$	**$3.16*10^{50}$**	**10^{28}**	$1.16*10^{32}$
Plank epoch > Grand unification epoch	10^{-43}	$3.17*10^{-51}$				
Grand unification epoch mid-phase	$5*10^{-37}$	**$1.58*10^{-44}$**	$3.17*10^{-44}$	**$3.16*10^{43}$**	**10^{25}**	$1.16*10^{29}$
Grand unification epoch > Inflationary	10^{-36}	$3.17*10^{-44}$				
Inflationary epoch mid-phase	$5*10^{-33}$	**$1.58*10^{-40}$**	$3.17*10^{-40}$	**$3.16*10^{39}$**	**$5*10^{23}$**	$5.8*10^{27}$
Inflationary epoch > Electroweak epoch	10^{-32}	$3.17*10^{-40}$				
Electroweak epoch mid-phase	$5*10^{-13}$	**$1.58*10^{-20}$**	$3.17*10^{-20}$	**$3.16*10^{19}$**	**150 billion eV (150 GeV)**	$1.74*10^{15}$
Electroweak epoch > Quark epoch	10^{-12} (one trillionth of a second)	$3.17*10^{-20}$				
Quark epoch mid-phase	$5*10^{-06}$	**$1.58*10^{-13}$**	$3.17*10^{-13}$ of a year (~1 millionth of a second)	**$3.16*10^{12}$ (3.16 trillion phase transitions per year)**	**75.1 billion eV (75.1 GeV)**	$8.71*10^{14}$ (871 trillion K)
Quark epoch > Hadron epoch	10^{-05} (0.00001, 10 millionths of a second)	$3.17*10^{-13}$				
Hadron epoch mid-phase	0.500005	**$1.58*10^{-8}$**	$3.17*10^{-8}$ of a year (~1 second)	**$3.16*10^{7}$ (31.6 million phase transitions per year)**	**75.5 million eV (75.5 MeV)**	$8.76*10^{11}$ (876 billion K)
Hadron epoch > Lepton epoch	1 second since the Big Bang Singularity	$3.17*10^{-8}$				
Lepton epoch, Neutrino decoupling, mid-phase	5.5 seconds	**$1.74*10^{-7}$**	$2.87*10^{-7}$ of a year (~9 seconds)	**$3.51*10^{6}$ (3.51 million phase**	**550,000 (550 KeV)**	$6.38*10^{9}$ (6.38 billion K)

Phases of the universal complexity growth	*t – t** (**seconds** since the Big Bang Singularity)	*t – t** (**years** since the Big Bang Singularity)	*Time between phases (years)*	*Universal evolutionary megade-volopment rate (phase transitions per year)*	Radiation temperature (energy) of the Universe, in electronvolts (eV)	Radiation temperature (energy) of the Universe, in Kelvins (K)
				transitions per year)		
Lepton epoch > Big Bang nucleosynthesis	10 seconds	$3.17*10^{-7}$				
Big Bang nucleosynthesis mid-phase	505 seconds	**$1.60*10^{-5}$**	$3.14*10^{-5}$	**$3.19*10^{4}$ (31,900 phase transitions per year)**	**50,500 (50.5 KeV)**	$5.86*10^{8}$ (586 million K)
Big Bang nucleosynthesis > Photon epoch	1000 seconds	$3.17*10^{-5}$				
Photon epoch mid-phase	$2.84*10^{11}$	**$9.0*10^{3}$ (9 thousand years since the B. Bang Singularity)**	$1.8*10^{4}$ (18 thousand years)	**$5.56*10^{-5}$ (5.56 phase transitions per 100 thousand years)**	**500 eV**	$5.86*10^{6}$ (5.86 million K)
Photon epoch > Recombination	$5.68*10^{11}$	$1.8*10^{4}$ (18 thousand years)				
Recombination mid-phase	$6.12*10^{12}$	**194 thousand years AS**	$3.52*10^{5}$ (352 thousand years)	**$2.84*10^{-6}$ (2.28 phase transitions per 1 million years)**	**1 eV**	$1.16*10^{4}$ (11.6 thousand K)
Recombination > Dark ages	$1.17*10^{13}$	370 thousand years since the B. Bang Singularity				
Dark ages mid-phase	$2.37*10^{15}$	**75.2 million (13.7 billion years BP)**	$1.496*10^{8}$ (149.63 million years)	**$6.68*10^{-9}$ (6.68 phase transitions per 1 billion years)**	**0.203 eV**	2,350 K
Dark ages > Population III stars	$4.73*10^{15}$	150 million (13.625 billion years BP)				
Population III stars, earliest galaxies, reionization, mid-phase	$1.81*10^{16}$	**575 million (13.2 billion years BP)**	$8.5*10^{8}$ (850 million years)	**$1.18*10^{-9}$ (1.18 phase transitions per 1 billion years)**	**0.0034 eV**	39.5 K
Population III stars > 2nd generation of stars	$3.16*10^{16}$	1 billion (12 billion years BP)				

Phases of the universal complexity growth	*t – t** (**seconds** since the Big Bang Singularity)	*t – t** (**years** since the Big Bang Singularity)	*Time between phases (years)*	*Universal evolutionary megade-volopment rate (phase transitions per year)*	Radiation temperature (energy) of the Universe, in electronvolts (eV)	Radiation temperature (energy) of the Universe, in Kelvins (K)
First 3rd generation stars appear against the background of predominance of the 2nd generation of stars, medium complexity galaxies, primitive planets, primitive chemical evolution, mid-phase	$1.61*10^{17}$	**5.1 billion (8,7 billion years BP)**	8.20E+09 $8.2*10^{9}$ (8.2 billion years)	**$1.22*10^{-10}$ (1.22 phase transitions per 10 billion years)**	**$1.89*10^{3}$ eV**	22 K
Predominance of the 2nd population of stars > predominance of the 3rd generation of stars	$2.90*10^{17}$	9.2 billion (4.6 billion years BP)				
Predominance of the 3rd generation of stars, complex galaxies, complex planets, complex chemical evolution	After $2.90*10^{17}$	After 9.2 billion years AS (after 4.6 billion years BP)	?	?	**$3.79*10^{-4}$ eV**	4.4 K

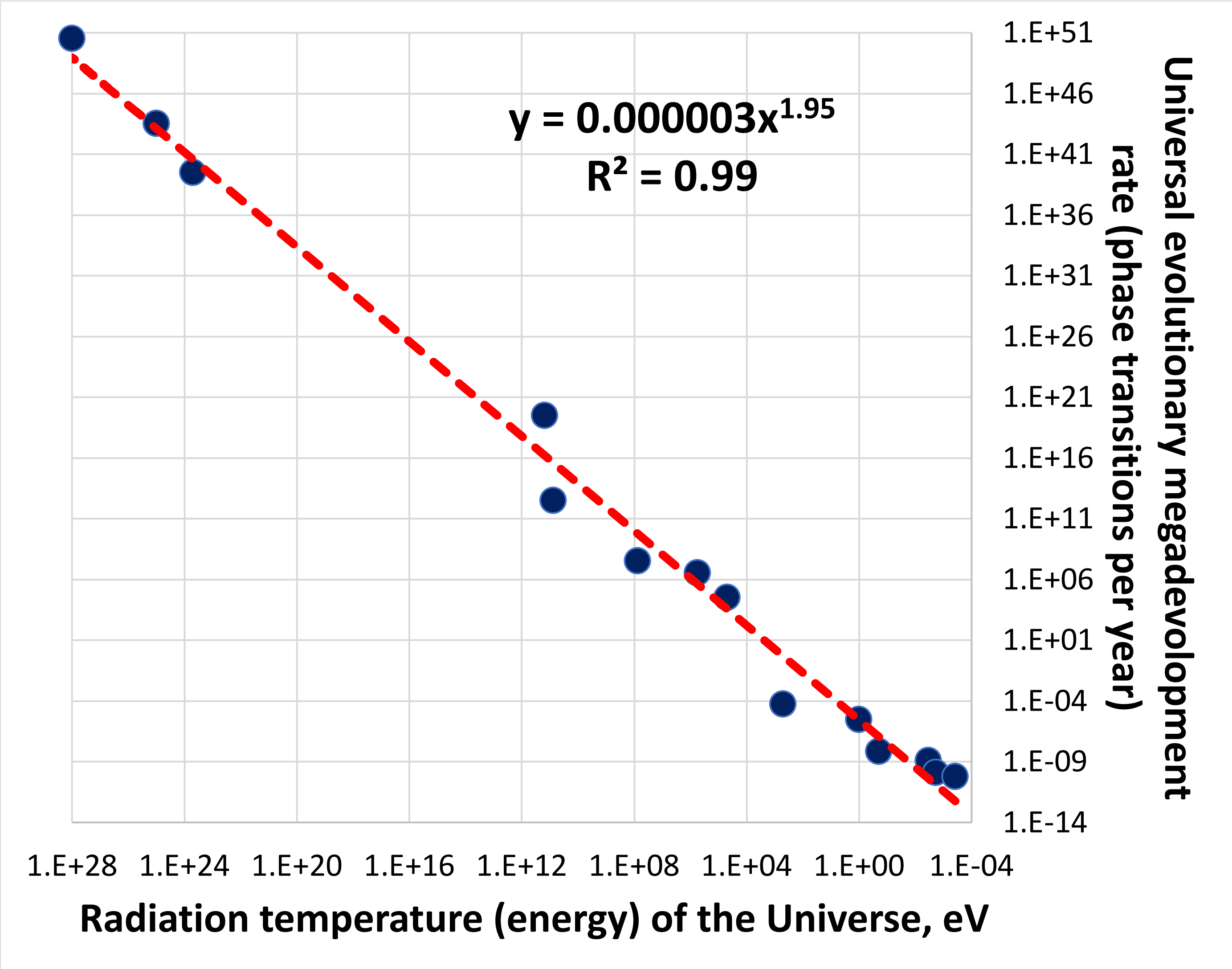


Fig. 16 Relationship between the radiation temperature (energy) of the Universe (eV) and universal evolutionary megadevolopment rate (phase transitions per year). Scatterplot of the phases of the growth of complexity in the Universe, with the fitted power-law regression line **(log-log scale, with reverse order of values along the x-axis)**

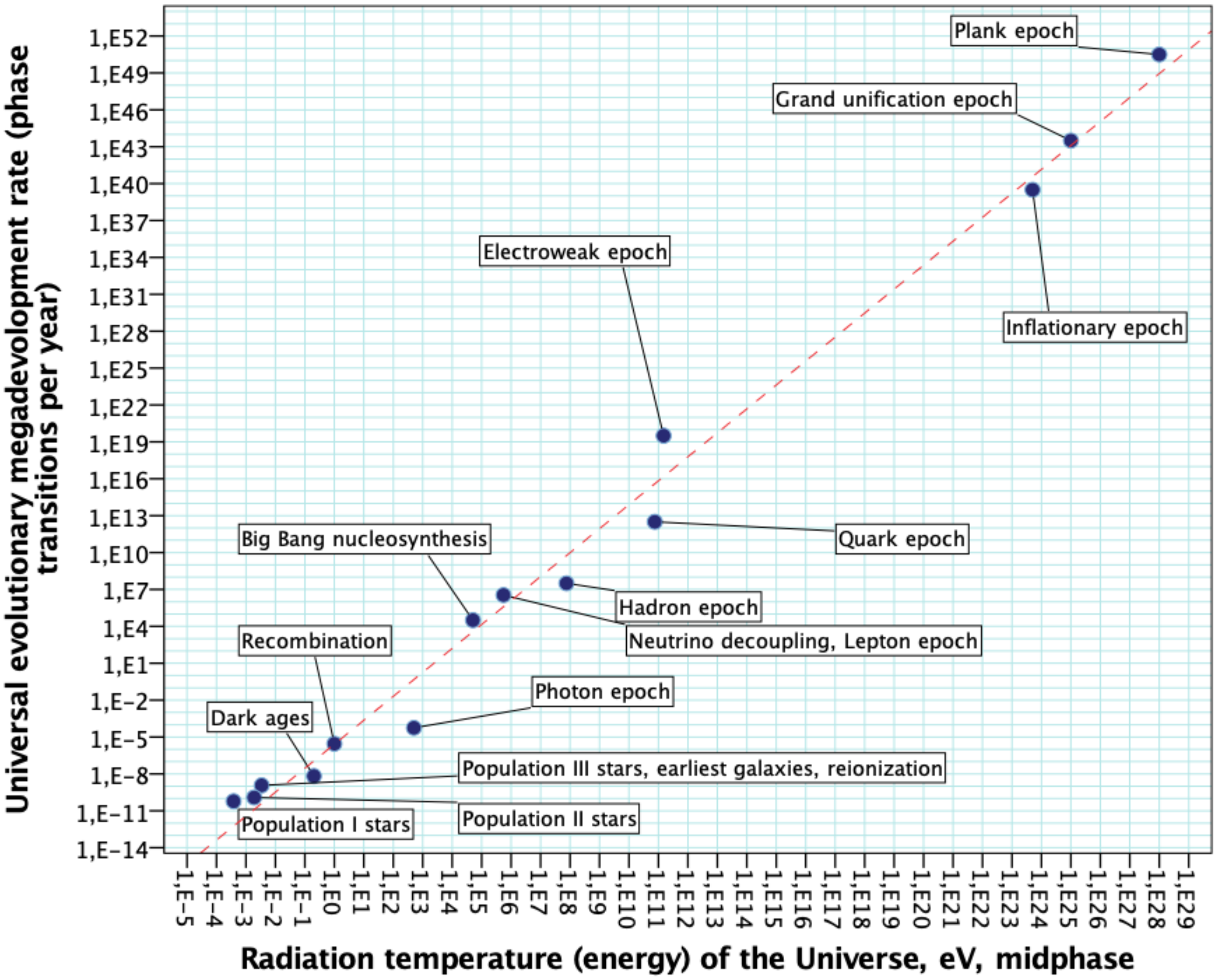


Fig. 17 Relationship between the radiation temperature (energy) of the Universe (eV) and universal evolutionary megadevolopment rate (phase transitions per year). Scatterplot of the phases of the growth of complexity in the Universe, with the fitted power-law regression line **(log-log scale, with direct order of values along the x-axis, for the whole range of values)**

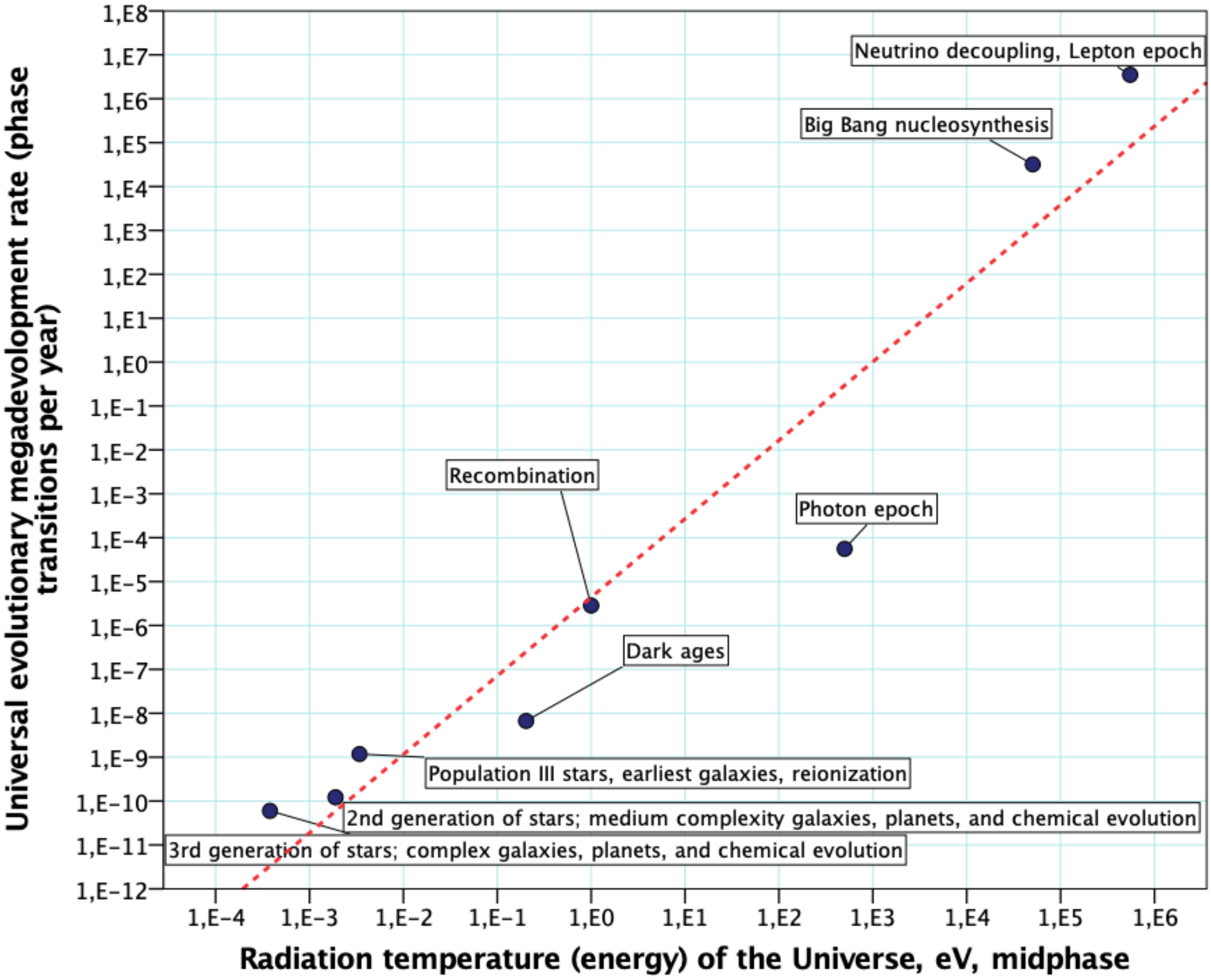
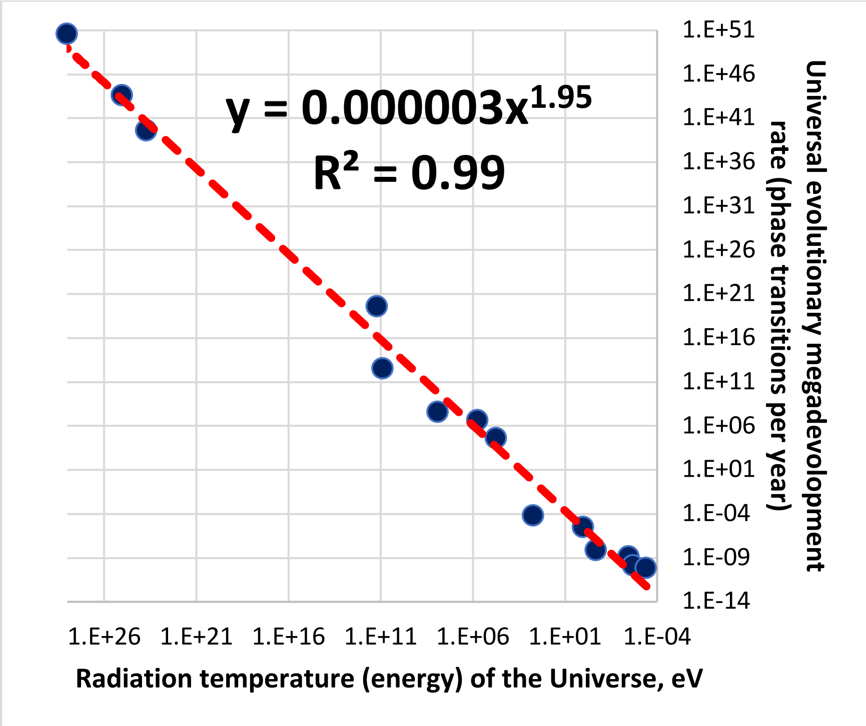


Fig. 18 Relationship between the radiation temperature (energy) of the Universe (eV) and universal evolutionary megadevolopment rate (phase transitions per year). Scatterplot of the phases of the growth of complexity in the Universe, with the fitted power-law regression line **(log-log scale, with direct order of values along the x-axis, for energy values < 1 MeV)**



Relationship between radiation temperature (energy) of the Universe (eV) and universal evolutionary megadevolopment rate (phase transitions per year)
$y = 0.000003{*}x^{1.95}$ ($R^2 = 0.99$), where y is the universal evolutionary megadevolopment rate (phase transitions per year); $x = E$ is the radiation temperature (energy) of the Universe (eV); $y = 0.000003{*}E^2$; $\boldsymbol{y = C_4{*}E^2}$.

$y = \frac{0.55}{t-t^*} = \frac{C_1}{t-t^*} = \frac{C_1}{x}$; $x = t - t^*$	$y = 0.000003 * E^2 = C_4 * E^2$
$C_4 * E^2 = \frac{C_1}{x}$	
$E^2 = \frac{C_1}{C_4}\frac{1}{x} =$	
$E^2 = \frac{0.55}{0.000003}\frac{1}{x}$	
$E^2 = \frac{188333}{x}$	
$E = \sqrt{\frac{188333}{x}}$	
$E = \frac{428}{\sqrt{x}} = 428x^{-0.5} \approx 400x^{-0.5}$	

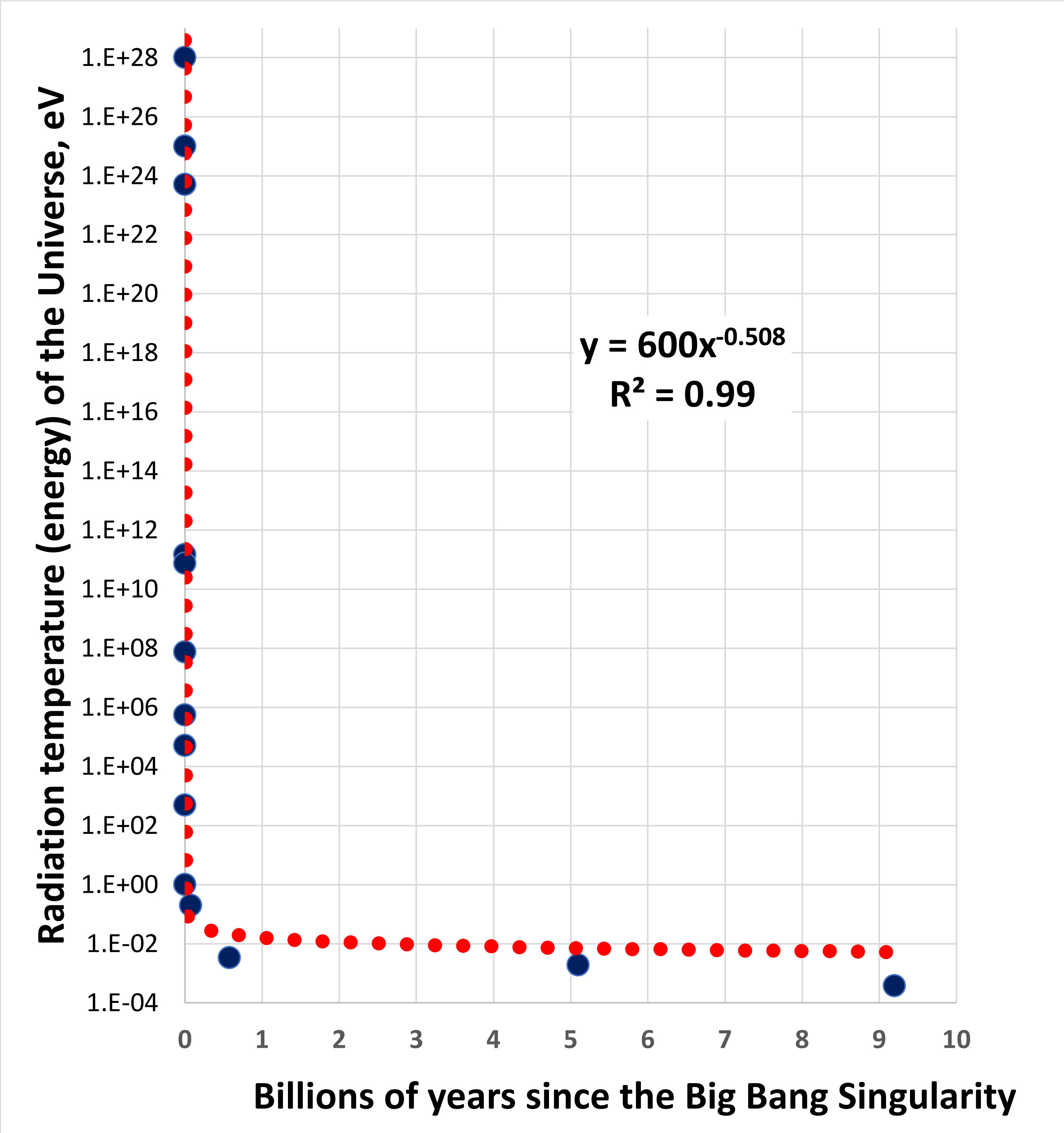


Fig. 19 Correlation between the time since the Big Bang Singularity (years) and radiation temperature (energy) of the Universe (eV). Scatterplot of the phases of the growth of complexity in the Universe, with the fitted power-law regression line **(with a logarithmic scale for the Y-axis)**

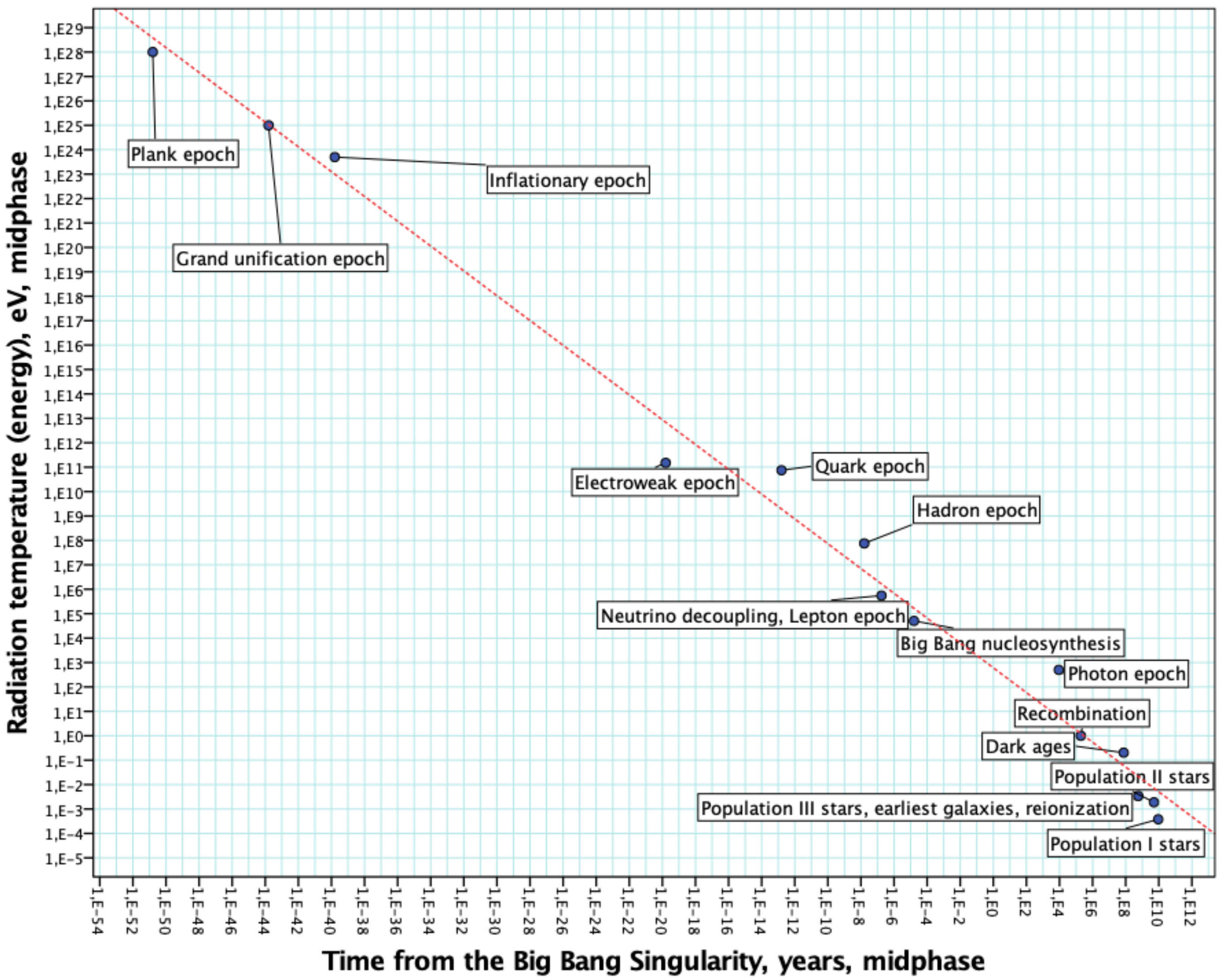


Fig. 20 Correlation between the time since the Big Bang Singularity (years) and radiation temperature (energy) of the Universe (eV). Scatterplot of the phases of the growth of complexity in the Universe, with the fitted power-law regression line **(log-log scale)**

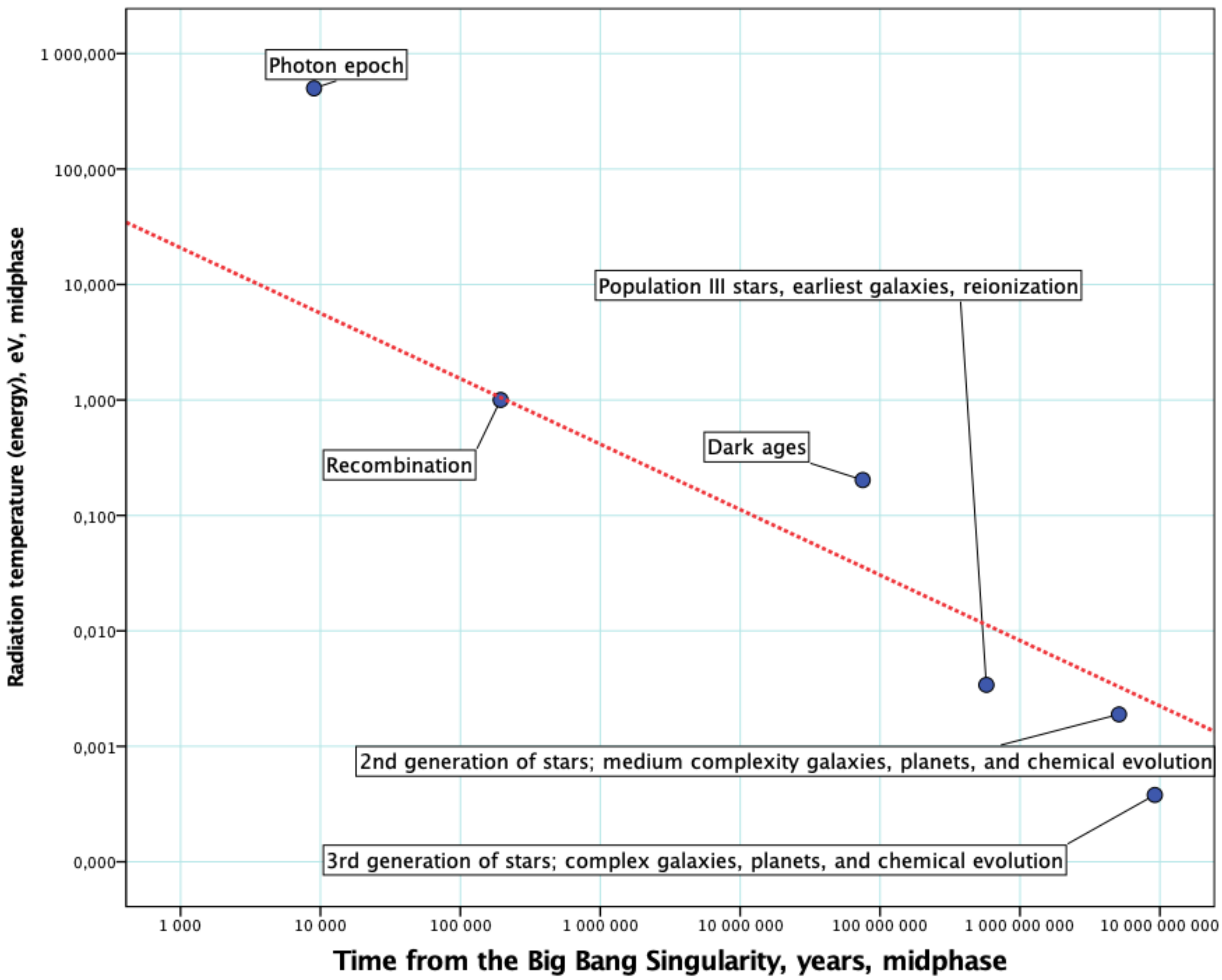
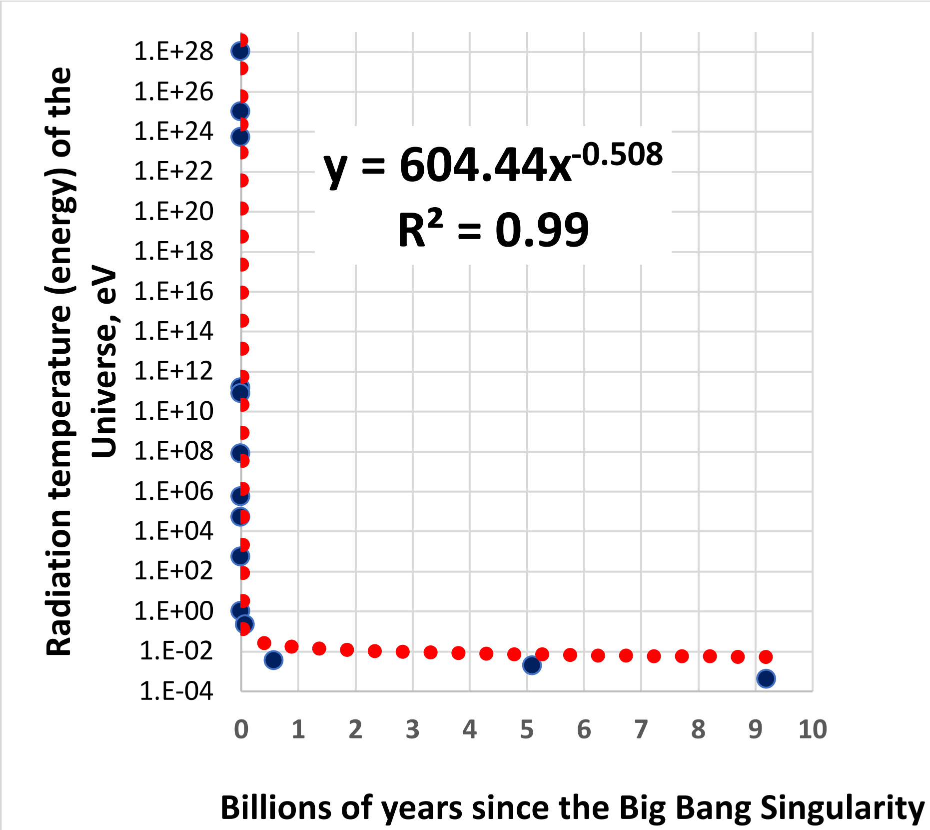
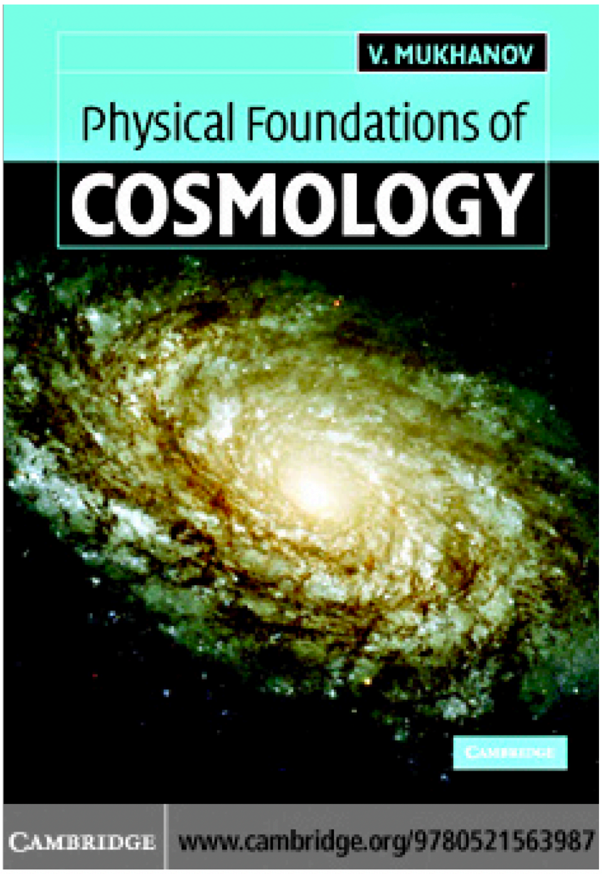


Fig. 21 Phases of the growth of complexity in the Universe **since 1000 years after the Big Bang Singularity.** Correlation between the time since the Big Bang Singularity (years) and radiation temperature (energy) of the Universe (eV). Scatterplot of the phases of the growth of complexity in the Universe, with the fitted power-law regression line **(log-log scale)**



Relationship between time since the Big Bang Singularity (years) and radiation temperature (energy) of the Universe (eV)
$y = E = 604.3 * x^{-0.508}$ ($R^2 = 0.99$), where $y = E$ is the radiation temperature (energy) of the Universe (eV); x is the time since the Big Bang Singularity (t^* = 13.8 biillion BP); $x = t - t^*$; $E = \frac{604}{(t - t^*)^{0.508}} = \frac{604}{(t - t^*)^{0.5}}$; $E = \frac{604}{\sqrt{t - t^*}}$; $\boldsymbol{E = \frac{C_3}{\sqrt{t - t^*}}}$ $E = \frac{604}{\sqrt{t - 13.8 \cdot 10^9 \text{BCE}}}$.



Problem 3.3 Dark energy with equation of state $w = -1/3$ leads to a term $\propto 1/a^2$ in the Friedmann equation (1.67). How can we nevertheless distinguish it from the spatial curvature term, k/a^2, in an open universe?

3.2 Brief thermal history

The temperature of the cosmic radiation decreases as the universe expands. It is unambiguously related to the redshift,

$$T_\gamma(z) = T_{\gamma 0}(1 + z), \tag{3.4}$$

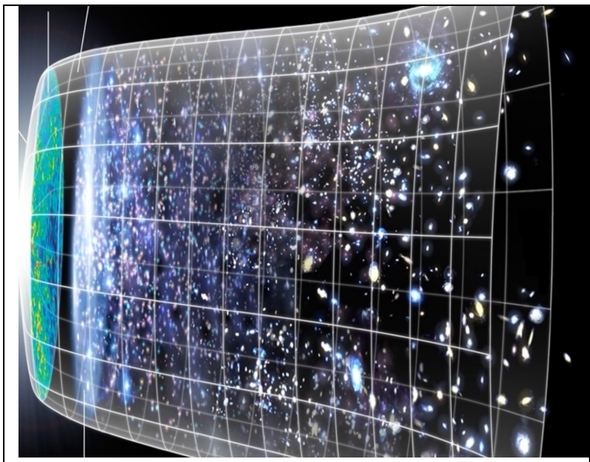
and can be used as an alternative to time or redshift to parameterize the history of the universe. To obtain an estimate for the temperature expressed in MeV, at the time t measured in seconds, we can use the formula

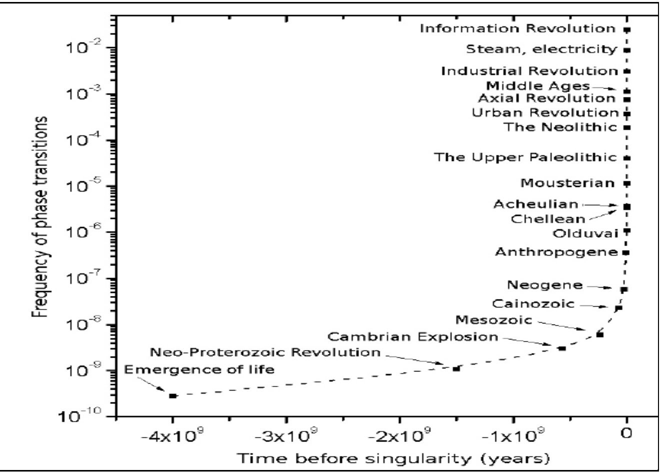
$$T_{\text{MeV}} \simeq \frac{O(1)}{\sqrt{t_{\text{sec}}}},$$

$$\boldsymbol{E = \frac{C_3}{\sqrt{t - t^*}}}$$

Decelerating universal (cosmic) evolutionary development	
Relationship between time since the Big Bang Singularity (***t-t****, years) and universal evolutionary megadevolopment rate (***y***, phase transitions per year)	$y = \frac{C_1}{t - t^*}$
Relationship between time since the Big Bang Singularity (***t-t****, years) and radiation temperature (energy) of the Universe (***E***, eV)	$E = \frac{C_3}{\sqrt{t - t^*}}$
Relationship between radiation temperature (energy) of the Universe (***E***, eV) and universal evolutionary megadevolopment rate (***y***, phase transitions per year)	$y = C_4 * E^2$

Decelerating universal (cosmic) evolutionary development		Accelerating global (biosocial) evolutionary development	
Relationship between time since the Big Bang Singularity (***t-t****, years) and universal evolutionary megadevolopment rate (***y***, phase transitions per year)	$$y = \frac{C_1}{t - t^*}$$	Relationship between time till the 21st century singularity (***t*-t***, years) and global (biosocial) evolutionary megadevolopment rate (***y***, phase transitions per year)	$$y = \frac{C_2}{t^* - t}$$
Relationship between radiation temperature (energy) of the Universe (***E***, eV) and universal evolutionary megadevolopment rate (***y***, phase transitions per year)	$$y = C_4 * E^2$$	Relationship between world energy production (***E***, TW) and global (biosocial) evolutionary megadevolopment rate (***y***, phase transitions per year)	$$y = C_5\sqrt{E}$$
Relationship between time since the Big Bang Singularity (***t-t****, years) and radiation temperature (energy) of the Universe (***E***, eV)	$$E = \frac{C_3}{\sqrt{t - t^*}}$$	Relationship between time till the 21st century singularity (***t*-t***, years) and world energy production (***E***, TW)	$$E = \frac{C_6}{(t^* - t)^2}$$




Information Revolution
Steam, electricity
Industrial Revolution
Middle Ages
Axial Revolution
Urban Revolution
The Neolithic
The Upper Paleolithic
Mousterian
Acheulian
Chellean
Olduvai
Anthropogene
Neogene
Cainozoic
Mesozoic
Cambrian Explosion
Neo-Proterozoic Revolution
Emergence of life
Frequency of phase transitions
Time before singularity (years)
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
$-4x10^9$
$-3x10^9$
$-2x10^9$
$-1x10^9$
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