Comparing and Contrasting Big History Singularity Trends of the Big Bang and Terrestrial Evolution

Andrey Korotayev

1 Introduction

The point that within the Big History the decelerating growth of complexity in the Universe observed after the Big Bang can be contrasted with the accelerating growth of complexity traced on our planet for four billion years after the emergence of life on the Earth has been already noticed on quite a number of occasions (e.g., Aunger, 2007; Faixat, 2022; LePoire, 2014, 2016, 2020b; Nazaretyan, 2017b; Panov, 2007, 2008; Panov et al., 2020; Tsirel, 2009).

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A. Korotayev (✉)
HSE University, Moscow, Russia
e-mail: akorotayev@gmail.com

Eurasian Center for Big History and System Forecasting, Institute of Oriental Studies, Russian Academy of Sciences, Moscow, Russia

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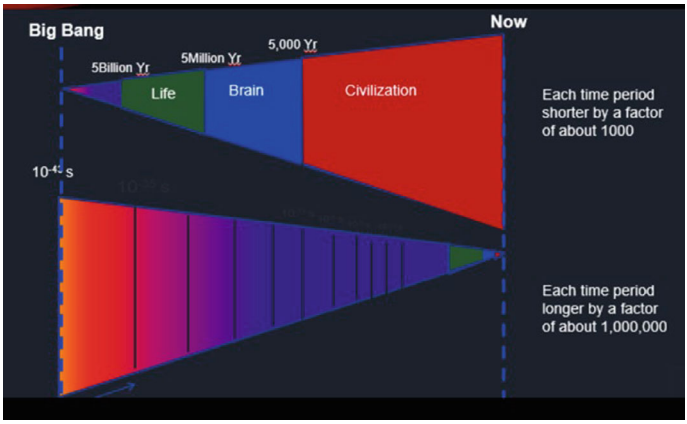

Fig. 1 Two contrasting views of time scales. *Source* LePoire (2014)

However, till now nobody seems to have undertaken a detailed mathematical comparison of these patterns. In fact, by now a rather thorough mathematical analysis has been only performed as regards the global pattern of accelerating evolution of the last 4 billion years.[1]

David LePoire appears to be the only person to have conducted some mathematical comparison of the two abovementioned patterns (LePoire, 2014, see Fig. 1).

However, this has been only published as a presentation at the 2nd International Big History Association Conference at Dominican College in San Rafael, CA in August 2014 (LePoire, 2014) and it does not appear to have been noticed by big historians. In addition, in this presentation, his analysis of the post-Big Bang universal evolution deceleration pattern, while being basically correct, was rather brief and lacked much detail (unlike his later very thorough and detailed mathematical analysis of the accelerating growth of complexity traced on our planet for four billion years after the emergence of life on the Earth [LePoire, 2016, 2020a, 2020b]).

This chapter aims at filling this gap by providing a more detailed quantitative analysis of the two abovementioned complexity growth patterns in the Big History. In addition, my comparative analysis is in no way a repetition of the one performed by David LePoire in 2014, as the comparative methodology I apply is quite different

[1] See von Foerster et al. (1960), Hoerner (1975), Taagepera (1976, 1979), Jantsch (1980), Kapitza (1992, 1996a, 1996b, 1999, 2003, 2006, 2007, 2010), Kremer (1993), Ekstig (1994, 2007, 2010a, 2010b, 2011, 2012, 2015, 2017), Johansen and Sornette (2001), Kurzweil (2001, 2005), Modis (2002, 2003, 2020), Tsirel (2004), Korotayev (2005, 2006a, 2006b, 2007, 2013, 2018, 2020a, 2020b), Panov (2004, 2005, 2011, 2017, 2020), Grinchenko (2006), Korotayev and Khaltourina (2006), Korotayev et al., (2006a, 2006b, 2015, 2016), Grinin (2006), Markov and Korotayev (2007, 2008), Grinin and Korotayev (2009, 2015), Grinchenko and Shchapova (2010, 2020), Markov et al. (2010), Korotayev and Malkov (2012, 2016), Grinin et al., (2020a; 2020b2013, 2014, 2015), Korotayev and Grinin (2013), Korotayev and Markov (2014, 2015), LePoire (2014, 2015a, 2015b, 2016, 2020a, 2020b), Korotayev and Zinkina (2017), Podlazov (2017), Dobrolyubov (2020), Fomin (2020), Malkov (2020), Widdowson (2020), and Faixat (2022).

from LePoire's. Thus, my analysis does not contradict his, but rather complements it.

This chapter is structured as follows. In its first part, I present a summary of my previous systematic quantitative analysis of the accelerating global (biosocial) complexity growth observed for about 4 billion years on our planet. In the second part, I apply the same methodology that I have applied to analyze this accelerating pattern to the analysis of decelerating universal complexity growth evidenced in the Universe for a few billions of years since the Big Bang Singularity (around 13.8 billion years BP). The third part offers a systematic comparison of the both patterns, whereas the fourth spells out its implications for the Big History periodization.

2 Summary of Previous Results of the Accelerating Complexity Growth on Our Planet

The results of our analysis of the Modis–Kurzweil series of the "global complexity jumps", yielding the global complexity growth rate (see Modis, 2002, 2003, 2020; Kurzweil, 2005)[2] can be found in Fig. 2 (note that our mathematical analysis identified the Singularity date for this time series as 2029 CE).

Figure 3 is presented in the double logarithmic scale.

As we see, our power-law regression of this time series identifies the following best fit equation describing this time series in an almost ideally accurate ($R^2 = 0.999$) way:

$$y = \frac{2.054}{x^{1.003}} \tag{1}$$

where y is the global complexity growth rate, x is the time remaining till the Singularity, and 2.054 and 1.003 are constants.

Note that the denominator's exponent (1.003) turns out to be only negligibly different from 1 (well within the error margins); hence, there are all grounds to use this equation in the following simplified form:

$$y = \frac{2.054}{x}, \tag{2}$$

where y is the global complexity growth rate, x is the time remaining before the Singularity, and 2.054 is a constant.

Of course, x (the time remaining till the Singularity) at the moment of time t equals $t^* - t$, where t^* is the time of Singularity. Thus,

$$x = t^* - t.$$

[2] For a very detailed description of this time series, as well as the methodology that I applied to its analysis see Korotayev (2018, 2020b).

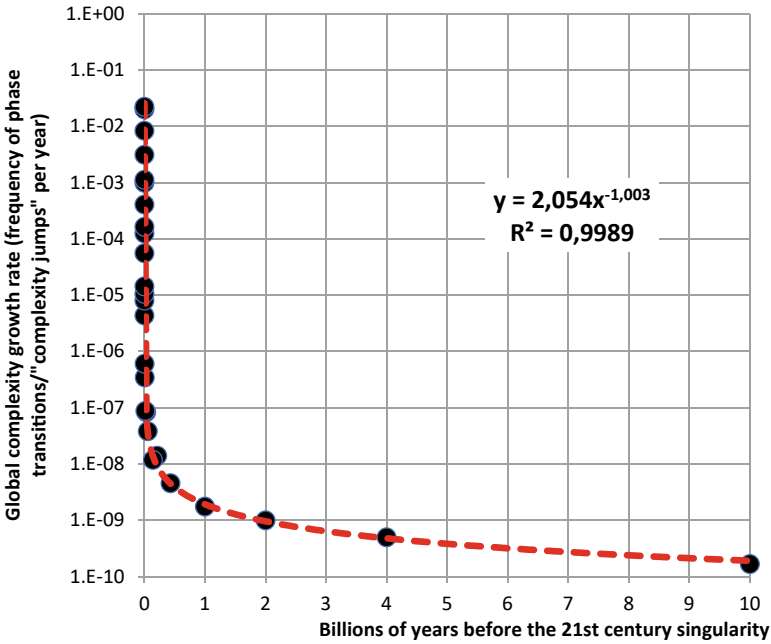

Fig. 2 Scatterplot of the "complexity jumps" from the Modis–Kurzweil list with the fitted power-law regression line (with a logarithmic scale for the Y-axis)—for the Singularity date identified as 2029 CE with the least squares method

Hence, Eq. (2) can be re-written in the following way:

$$y_t = \frac{2.054}{t^* - t}, \tag{3}$$

where y_t is the global complexity growth rate at time t, t^* is the time of Singularity, and 2.054 is a constant.

Finally, let us recollect that our power-law analysis of the transformed Modis–Kurzweil series has identified the Singularity date as 2029 CE. Thus, Eq. (3) can be further re-written in the following way:

$$y_t = \frac{2.054}{2029 - t}. \tag{4}$$

Of course, in a more general form it should be written as follows:

$$y_t = \frac{C}{t^* - t}, \tag{5}$$

where C and t^* are constants.

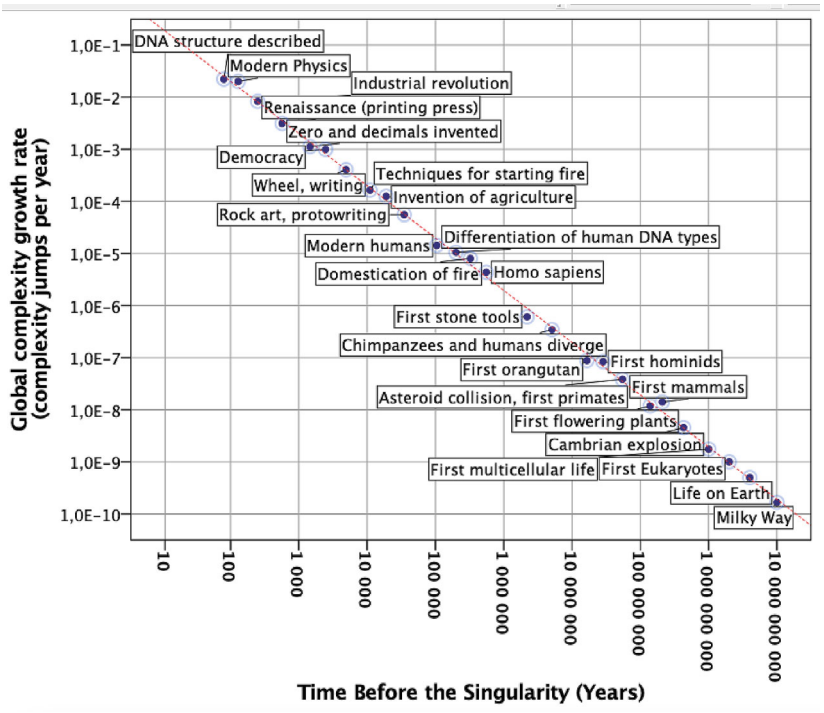

Fig. 3 Scatterplot of the phase transition points from the Modis–Kurzweil list with the fitted power-law regression line (double logarithmic scale)—for the Singularity date identified as 2029 CE with the least squares method

Now, let us apply a similar methodology to analyze mathematically the series of global macroevolutionary "phase transitions"/ "biospheric revolutions" compiled by Alexander Panov (2005; see also Panov, 2008, 2011, 2017).

Note that Alexander Panov and Theodore Modis compiled their time series entirely independently of each other. As suggest my personal communications with both Panov and Modis, none of them knew that at almost the same time[3] in another part of Europe another person compiled a similar time series (Alexander Panov worked in Moscow, whereas Theodore Modis worked in Geneva). They relied on entirely different sources and the resultant time series turned out to be very far from being identical (see, e.g., Table 1).

As one can see for a major part of the planetary history (between the Cambrian explosion and the formation of *Homo sapiens sapiens*) the correlation between the two series is really weak; they look as really independent (and rather different) series.

[3] Modis first presented his results in an article in *Technological Forecasting and Social Change* (that Panov only read in March 2018 after it was sent to him by me) in 2002, whereas Panov first presented his results next year at the Academic Seminar of the State Astronomic Institute in Moscow.

Table 1 Correlation between the phase transition lists of Modis and Panov for the period between 400 million years ago and 150,000 years ago

Modis–Kurzweil series	Panov (2005) series
(6) First mammals, first birds, first dinosaurs—*210 million years ago* **(7) First flowering plants**, oldest angiosperm fossil—*139 million years ago* **(8) First primates/** asteroid collision/ mass extinction (including dinosaurs)—*54.6 million years ago* **(9) First hominids**, first humanoids—*28.5 million years ago* **(10) First orangutan**, origin of proconsul—*16.5 million years ago* **(11) Chimpanzees and humans diverge**, earliest hominid bipedalism—*5.1 million years ago* **(12) First stone tools**, first humans, *Homo erectus—2.2 million years ago* **(13) Emergence of *Homo sapiens*—***555,000 years ago* **(14) Domestication of fire /** *Homo heidelbergensis—325,000 years ago* **(15) Differentiation of human DNA types**—*200,000 years ago*	**(3) Reptiles revolution** (The beginning of Mesozoic era)—*235 million years ago* **(4) Mammalia revolution** (The beginning of the Cenozoic era). Dinosaurs died out. Mammalia animals became the leader of the evolution on the terra firma.—*66 million years ago* **(5) Hominoid revolution** (The beginning of the Neogene period). A big evolution explosion of Hominoidae (apes)—*22.5 million years ago* **(6) The beginning of Quaternary period (Anthropogene) /** The first primitive Homo genus (hominidae) separated from hominoidae—*4.4 million years ago* **(7) Palaeolithic revolution /** Homo habilis, the first stone implements—*1.8 million years ago* **(8) The beginning of Chelles period**—*650,000 years ago.* Fire, Homo erectus **(9) The beginning of Acheulean period**. Standardized symmetric stone implements—*400,000 years ago*

Now, knowing all this, let us analyze Panov's time series the same way we have analyzed above the Modis–Kurzweil list of "canonical milestones". The results of such an analysis look as follows (see Fig. 4).

In the double logarithmic scale, the fit between the power-low model $y = 1.886/x^{1,01}$ (where x denotes number of years before the Singularity point defined as 2027 CE) and the empirical estimates of Panov looks as follows (see Fig. 5).

Actually, I expected that the equation best describing the Panov series should look fairly similar to the one best describing the Modis–Kurzweil one; but, to tell the truth, I did not expect that they would look SO SIMILAR (especially, keeping in mind that Modis and Panov relied on totally different sources, and that the resultant lists of "canonical milestones" were very far from being identical).

However, the resultant equations turned out to be EXTREMELY similar (this is especially striking taking into consideration the point that neither Modis, nor Panov tried to approximate their time series with Eq. (10/8)). Indeed, in the unsimplified form the power-law equation best describing the acceleration pattern in the Modis–Kurzweil series looks as follows (see Fig. 2):

$$y = \frac{2.054}{(2029 - t)^{1.003}}, \tag{1}$$

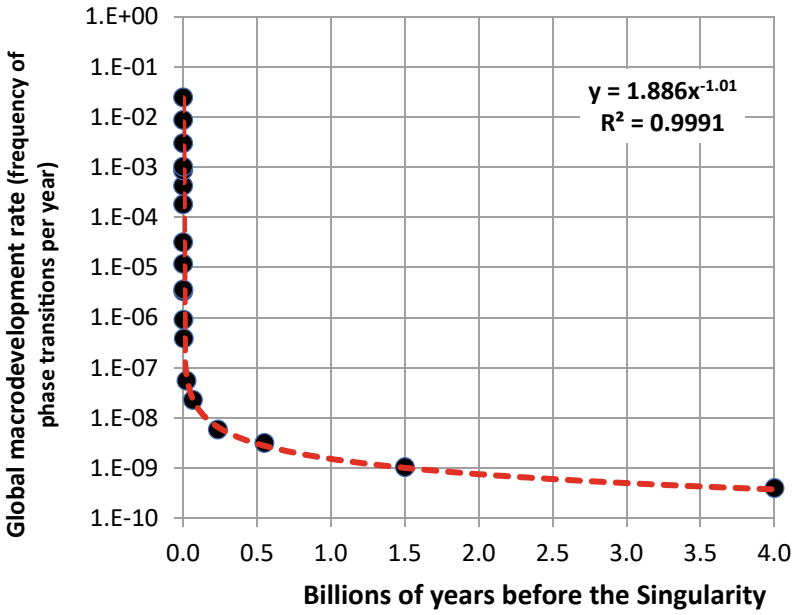

Fig. 4 Scatterplot of the phase transition points from Panov's list with the fitted power-law regression line (with a logarithmic scale for the Y-axis)—for the Singularity date identified as 2027 CE with the least squares method

where, let us recollect, y is the global complexity growth rate (number of phase transitions per a unit of time), and 2029 CE is the best-fit singularity point estimate.

In the meantime, the power-law equation best describing the acceleration pattern in the Panov (2005) series looks as follows (see Fig. 4):

$$y = \frac{1.886}{(2027 - t)^{1.01}}. \tag{6}$$

In general form, the respective equation looks as follows:

$$y = \frac{C}{(t^* - t)^{\beta}}. \tag{7}$$

This equation has three parameters—C, t^*, and β. Note that all the three parameters turn out to be extremely close for both Modis–Kurzweil and Panov.

It appears appropriate to recollect at this point that in their famous article published in the journal *Science* in 1960 von Foerster, Mora, and Amiot presented their results of the analysis of the world population growth pattern. They showed that between 1 and 1958 CE the world's population (N) dynamics can be described in an extremely accurate way with the following astonishingly simple equation:

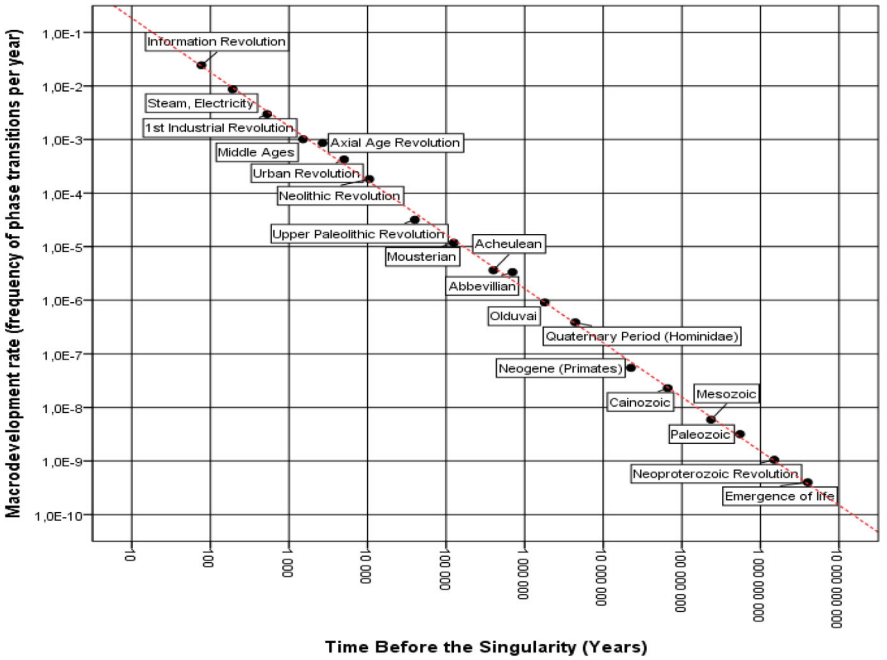

Fig. 5 Scatterplot of the phase transition points from Panov's list with the fitted power-law regression line (double logarithmic scale)—for the Singularity date identified as 2027 CE with the least squares method

$$N_t = \frac{C}{(t^* - t)^{0.99}}, \tag{8}$$

where N_t is the world population at time t, and C and t^* are constants, with t^* corresponding to the so called "demographic singularity". Parameter t^* 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" (von Foerster et al., 1960). Note that von Foerster and his colleagues detected the hyperbolic pattern of world population growth for 1 CE–1958 CE; later it was shown that this pattern continued for a few years after 1958, and also that it can be traced for many millennia BCE (Kapitza, 1996a, 1996b, 1999; Korotayev et al., 2006a, 2006b; Kremer, 1993; Podlazov, 2017; Tsirel, 2004). In fact, Kremer (1993) claims that this pattern is traced since 1,000,000 BP, whereas Kapitza (1996a, 1996b, 2003, 2006, 2010) even insists that it can be found since 4,000,000 BP.

It is difficult not to see that the world population growth acceleration pattern detected by von Foerster in the empirical data on the world population dynamics between 1 and 1958 turns out to be virtually identical with the one that has been detected above with respect to both Modis–Kurzweil and Panov series describing

the planetary macroevolutionary development acceleration. Note that the power-law regression has yielded for all the three series the value of exponent β being extremely close to 1 (1.003 for the Modis–Kurzweil series, 1.01 for Panov, and 0.99 for von Foerster).

However, the resultant proximity of parameter t^* (that is just the singularity time point) estimates is also really impressive (the power-law regression suggests 2029 for the Modis–Kurzweil series, 2027 for Panov series, and just the same 2027 for von Foerster series[4]).

As was the case with Eqs. (1) and (6) above, in von Foerster's Eq. (8) the denominator's exponent (0.99) turns out to be only negligibly different from 1, and as was already suggested by von Hoerner (1975) and Kapitza (1992, 1999), it can be written more succinctly as

$$N_t = \frac{C}{t^* - t}. \tag{9}$$

As we see the resultant equation turns out to be entirely identical with Eq. (5)[5] above that described so accurately the overall planetary macrodevelopment acceleration pattern since at list 4 billion years ago. Note that Eq. (9) has turned out to be as capable to describe in an extremely accurate way the world population dynamics (up to the early 1970s), as Eq. (5) is capable to describe the overall pattern of macredevopment acceleration (at least between 4 billion BCE and the present). We will show just an example of such a fit.

Let us take Eq. (9). Now replace t^* with 2027 (that is the result of just rounding of von Foester's number, 2026.87), and replace C with 215000.[6] This gives us a version of von Foerster–von Hoerner–Kapitza Eq. (9) with certain parameters:

$$N_t = \frac{215000}{2027 - t} \tag{10}$$

The overall correlation between the curve generated by von Foerster's equation and the most detailed series of empirical estimates looks as follows (see Fig. 6).

As we see, indeed, Eq. (10) has turned out to be as capable to describe in an extremely accurate way the world population dynamics (up to the early 1970s), as

[4] Note that the power-law regression that produced this value for the world populations series had been performed more than 50 years before a similar regression produced the same value of t^* for the Panov series (actually, the first regression was performed before the birth of the author of the present chapter). Still I would not take too seriously such astonishingly similar values of t^* parameter produced by different power-law regressions for very different time series in very different years; of course, there is a very high degree of coincidence here. In any case, as we will see below, there are no grounds at all to expect anything like Doomsday on Friday, November 13, A.D. 2026…

[5] Though the values of parameter C in Eqs. (5) and (9) are of course different.

[6] Note that all the calculations below of the world population are conducted in millions. Note also that the value of parameter C used by us is a bit different from the one used by von Foerster.

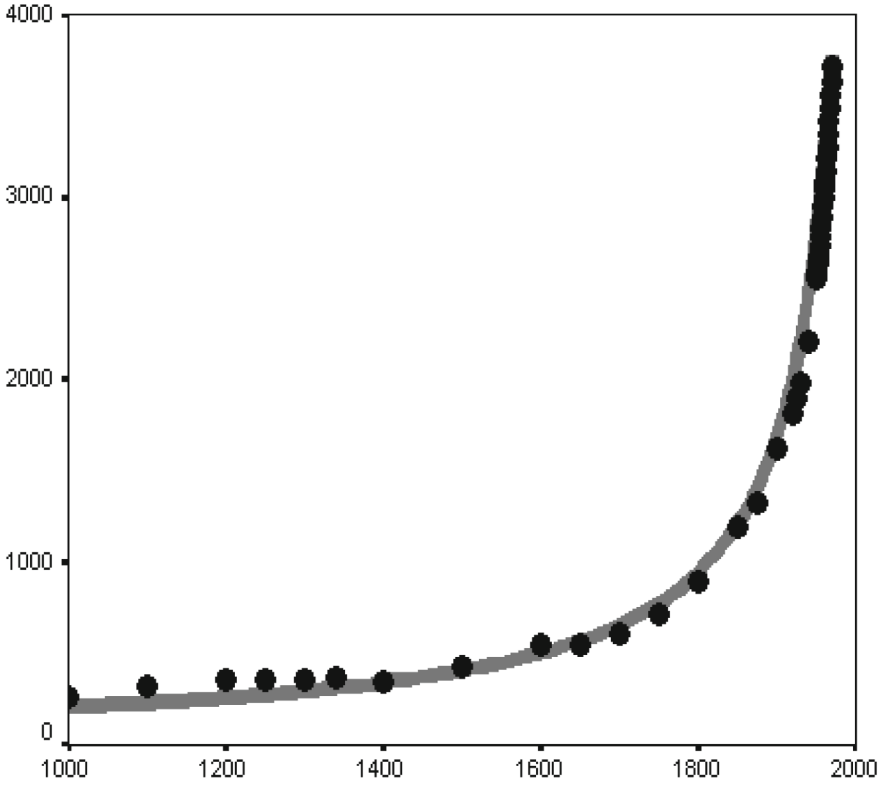

Fig. 6 Correlation between empirical estimates of world population (in millions, 1000–1970) and the curve generated by von Foerster's Eq. (3). *Note* Black markers correspond to empirical estimates of the world population by McEvedy and Jones (1978) for 1000–1950 and UN Population Division (2024) for 1950–1970. The grey curve has been generated by von Foerster's Eq. (10). $R^2 = 0.996$

Eq. (4) is capable to describe the overall pattern of global complexity growth rate acceleration (see Korotayev, 2018, 2020b for detail).

We have shown that that the fact that, up to the beginning of the 1970s, the world population size (N) and the global complexity growth rate (y) in the Panov series grew following the same law ($x_t = C/2027 - t$), is by no means a coincidence; it is rather a manifestation of a fairly deep pattern of the global evolution. Thus, at the social phase of universal and global history, the hyperbolic growth of the rate of increase in global complexity and the hyperbolic growth of the Earth's population are two closely related aspects of a single process. We have demonstrated that Eq. (9) can be derived from Eq. (5) and the other way around (e.g., Korotayev, 2020a, 2020b).

I must say that I had serious doubts when I first got across calculations of Panov and Modis (and I am not surprised that most historians get very similar doubts when they see their works). I had many complaints regarding the accuracy of many of their descriptions of their "phase transitions"/ "complexity jumps", their selection, and

their datings (see, e.g., Korotayev, 2015). I have only started taking their calculations seriously, when I analyzed myself the two respective time series compiled (as we have seen above) entirely independently by two independently working scientists using entirely different sources with a mathematical model not applied to their analysis either by Modis or by Panov, and found out that they are described in an extremely accurate way by an almost identical mathematical hyperbolic function—suggesting the actual presence of a rather simple hyperbolic planetary macroevolution acceleration pattern observed on the Earth for the last 4 billion years. This impression became even stronger when the equation describing the planetary macroevolution acceleration pattern turned out to be identical with the equation that was found by Heinz von Foerster in 1960 to describe in an extremely accurate way the global population growth acceleration pattern between 1 and 1958 CE.

But how seriously should we take the prediction of "singularity" contained in such mathematical models? Should we really expect with Kurzweil that around 2029 (see Ranj, 2016) we should deal with a few orders of magnitude acceleration of the technological growth (indeed, predicted by Eq. (4) if we take it literally[7])?

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, 2007: 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 (see Fig. 4) (see, e.g., Kapitza, 2003, 2006, 2007, 2010; Livi-Bacci, 2012; Korotayev et al., 2006a, 2006b, 2015; Grinin & Korotayev, 2015; UN Population Division, 2024), 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 slowdown, with a clear perspective of transition to a negative population growth rate (see Fig. 7).

In some respect, it may be said that von Foerster did discover the singularity of the human demographic history; it may be said that he detected that the human World System was approaching the singular period in its history when the hyperbolic accelerating trend that it had been following for a few millennia (and even a few

[7] This is done, for example, by Nazaretyan (2005, 2017a, 2017b, 2018, 2020).

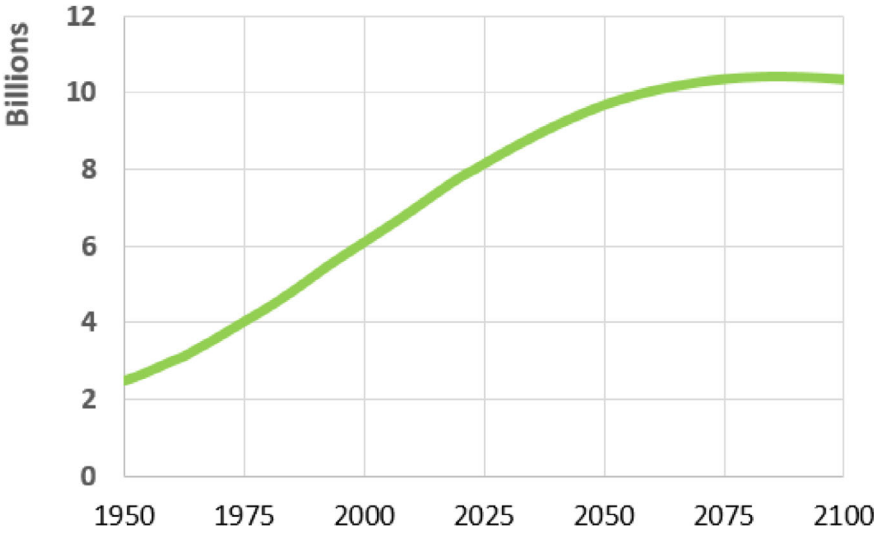

Fig. 7 World population dynamics (billions), empirical estimates of the UN Population Division for 1950–2022 with its middle forecast to 2100. *Data source* UN Population Division (2024)

millions of years according to some) would be replaced with an opposite decelerating trend. The process of this trend reversal has been studied very thoroughly by now (see, e.g., Caldwell et al., 2006; Chesnais, 1992; Choi, 2016; Dyson, 2010; Gould, 2009; Khaltourina & Korotayev, 2007; Korotayev, 2009; Korotayev et al., 2006a, 2006b; Livi-Bacci, 2012; Podlazov, 2017; Reher, 2011; Vishnevsky, 1976, 2005) and is known as the "global demographic transition" (Kapitza, 1999, 2003, 2006, 2010; Podlazov, 2017). Note that in case of global demographic evolution the transition from the hyperbolic acceleration to logistic deceleration started a few decades before the singularity point mathematically detected by von Foerster.

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. This is well supported by the growing body of evidence suggesting the start of the long term deceleration of the global techo-scientific and economic growth rates in the recent decades (see, e.g., Akaev, 2010; Gordon, 2012; Huebner, 2005; Khaltourina & Korotayev, 2007; Korotayev & Bilyuga, 2016; Korotayev & Bogevolnov, 2010; Krylov, 1999, 2002, 2007; Korotayev et al., 2010; LePoire, 2005, 2009, 2013, 2015a, 2015b, 2020a, 2020b; LePoire & Chandrankunnel, 2020; LePoire & Devezas, 2020; Maddison, 2007; Modis, 2002, 2005, 2012, 2020; Piketty, 2014; Popović, 2018; Teulings & Baldwin, 2014; Widdowson, 2020).

Now, let us sum up our quantitative analysis of the accelerating growth of complexity traced on our planet for four billion years since the emergence of life on the Earth.

It may be said that the general formula of the acceleration of the global complexity growth

$$y = \frac{C}{t^* - t} \tag{5}$$

can be described as follows:

- The rate of the global complexity growth increases when we approach the Singularity.
- As the time until the Singularity decreases n times, the global complexity growth rate increases the same n times.
- Thus, if the time until 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.

Let us apply now the same methodology that we have applied earlier to analyze the abovementioned accelerating pattern to the analysis of decelerating universal (cosmic) evolutionary development evidenced in the Universe for a few billions of years since the Big Bang Singularity.

3 Decelerating Universal (Cosmic) Evolutionary Development After the Big Bang

We have used the following time series for our analysis (shown in Table 2), taking into account the following phases of the universal complexity growth The major phase transitions and phases of complexity growth in the Universe, as well as their dating in seconds and years since the Big Bang Singularity, can be tentatively described as follows (see Table 2 and Fig. 8).

To identify an equation describing the post-Big-Bang decelerating growth of the complexity in the Universe we apply to the table above the same type of mathematical analysis that we applied earlier to the time series of Modis–Kurzweil and Panov. Thus, we correlate the frequency of phase transitions in the given Big History epoch with the time period separating this epoch from the Big Bang Singularity (see columns 3 and 5 in Table 2; the values used for calculations whose results are presented in Figs. 9 and 10 are highlighted with a bold font in columns 3 and 5 of Table 2).

As we see, our power-law regression of the time series of phase transitions of the post-Bing-Bang-Singularity complexity growth in the Universe outlined in Table 2 has identified the following best fit equation describing this time series:

$$y = \frac{0.549}{x^{0.998}}, \tag{11}$$

Table 2 Phase transitions and phases of the complexity growth in the Universe

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 complexity growth rate (phase transitions per year)	Radiation energy of the Universe, in electronvolts (eV)	Radiation energy (temperature) of the Universe, in Kelvins (K)
1	2	3	4	5	6	7
Planck epoch starts	0	0				
Planck epoch mid-phase	$5*10^{-44}$	**$1.58*10^{-51}$**	$3.17*10^{-51}$	**$3.16*10^{50}$**	**10^{28}**	$1.16*10^{32}$
Planck 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 epoch	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)

(continued)

Table 2 (continued)

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 complexity growth rate (phase transitions per year)	Radiation energy of the Universe, in electronvolts (eV)	Radiation energy (temperature) of the Universe, in Kelvins (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 s)	**$3.16*10^{7}$ (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 s since the Big Bang Singularity	$3.17*10^{-8}$				
Lepton epoch, Neutrino decoupling, mid-phase	5.5 s	**$1.74*10^{-7}$**	$2.87*10^{-7}$ of a year (~9 s)	**$3.51*10^{6}$ (3.51 million phase transitions per year)**	**550,000 (550 keV)**	$6.38*10^{9}$ (6.38 billion K)
Lepton epoch > Big Bang nucleosynthesis	10 s	$3.17*10^{-7}$				
Big Bang nucleosynthesis mid-phase	505 s	**$1.60*10^{-5}$**	$3.14*10^{-5}$	**$3.19*10^{4}$ (31,900 phase transitions per year)**	**50,500 (50.5 keV)**	$5.86*10^{8}$ (586 million K)
Big Bang nucleosynthesis > Photon epoch	1000 s	$3.17*10^{-5}$				

(continued)

Table 2 (continued)

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 complexity growth rate (phase transitions per year)	Radiation energy of the Universe, in electronvolts (eV)	Radiation energy (temperature) of the Universe, in Kelvins (K)
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				

(continued)

Table 2 (continued)

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 complexity growth rate (phase transitions per year)	Radiation energy of the Universe, in electronvolts (eV)	Radiation energy (temperature) of the Universe, in Kelvins (K)
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)				
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

(continued)

Table 2 (continued)

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 complexity growth rate (phase transitions per year)	Radiation energy of the Universe, in electronvolts (eV)	Radiation energy (temperature) of the Universe, in Kelvins (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

Data sources Baumann (2022), Chaisson (2001), Coc (2017), Coc et al. (2014), Gorbunov and Rubakov (2018), Hawking (2009), Karki (2010), Loeb (2006), May et al. (2008), Morison (2015), Mukhanov (2005), Panov (2008), Petter (2013), Ryden (2017), Spier (2010), and Sunyaev and Chuba (2009). Note that the list of phase transitions above does not include the transition from the radiation-dominated era to the matter-dominated one around 47 thousand years after the Singularity and the transition from the matter-dominated era to the dark-energy-dominated one [accompanied by the acceleration of the expansion of the Universe] around 9.8 billion years after the Singularity, as both of these important milestones of the cosmic history do not appear to have been accompanied by any clear increase in complexity. However, it is important to emphasize that our additional tests have indicated that their inclusion does not affect the results of our calculations in any significant way

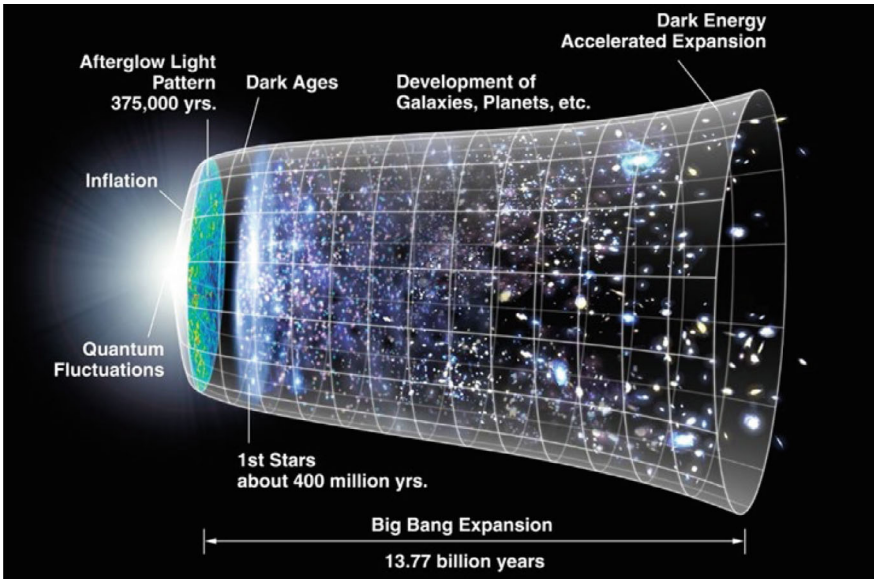

Fig. 8 Timeline of the universe. A representation of the evolution of the universe over 13.77 billion years. *Source* https://en.wikipedia.org/wiki/Big_History#/media/File:CMB_Timeline300_no_WMAP.jpg

where y is the universal complexity growth rate (phase transitions per year), x is the time elapsed since the Big Bang Singularity, and 0.549 and 0.998 are constants. Note that the fit between the theoretical curve generated by simple power-law Eq. (11) and the empirical estimates of the complexity growth deceleration dynamics in the Universe spelled out in Table 2 ($R^2 = 0.999996$) has turned to be even higher than we observed above with respect to very similar power-law equations describing the global complexity growth acceleration pattern as regards Modis–Kurzweil series (Eq. (1); $R^2 = 0.9989$) and Panov series (Eq. (2); $R^2 = 0.9991$). Note that the difference of the denominator's exponent from 1 ($0.998 - 1 = -0.002$) turns out to be as negligible as we could see it above with Eq. (1) describing the Modis–Kurzweil series ($1.003 - 1 = 0.003$) and Eq. (6) describing the Panov series ($1.01 - 1 = 0.01$). Hence, as we have seen this above as regards Eqs. (1) and (6), there are all grounds to use this equation in the following simplified form:

$$y = \frac{0.549}{x}, \tag{12}$$

where y is the universal complexity growth rate (phase transitions per year), x is the time elapsed since the Big Bang Singularity, and 0.549 is a constant.

However, the correlation seems too good. In fact, this type of correlation follows from the type of data and the definition of the complexity growth rate. The data has large relative differences in time such that the difference between the time of an

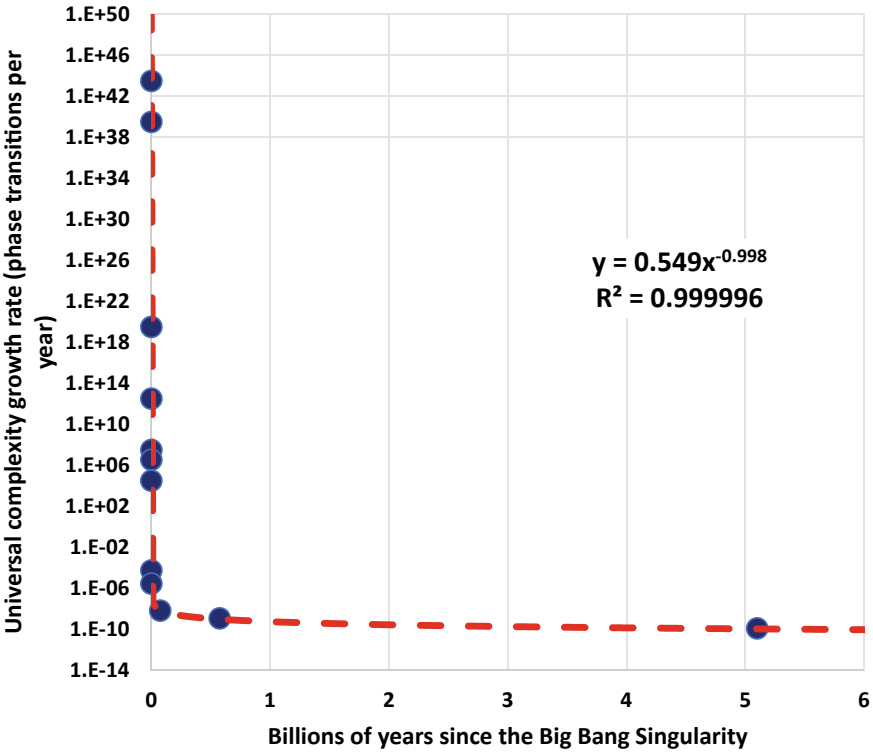

Fig. 9 Correlation between the time since the Big Bang Singularity and universal complexity growth rate = evolutionary megadevelopment rate of the Universe (phase transitions per year). Scatterplot of the phases of the growth of complexity in the Universe, with the fitted power-law regression line **(with a logarithmic scale for the Y-axis)**

event and its predecessor, at a much earlier time, is just the time of the event. When complexity is defined as the reciprocal of this time difference, the curve is effectively being defined such that C(t) = A/t, independent of the data. So, this does not seem to be a sufficient test for a singularity trend.

A different formulation of a singularity is that equally weighted events would occur with a geometric sequence in time from (or toward) the singularity time. For the Panov and Modis sequences of the biosocial evolution on earth this factor is about a third. This would mean that the next event occurs at about 1/3 of the time before the singularity time. So, an event occurring at 1,500 years before the singularity time would be expected to be followed by an event at 500 years (1500/3) before the singularity time, followed by the next event at 167 years before the singularity time. With this fractal sequence there would be an infinite number of events before the project singularity time. Of course, this would never happen in a real physical sequence. This can be analyzed by placing the events sequentially and using the event number to perform a correlation. A true geometric sequence of events would have

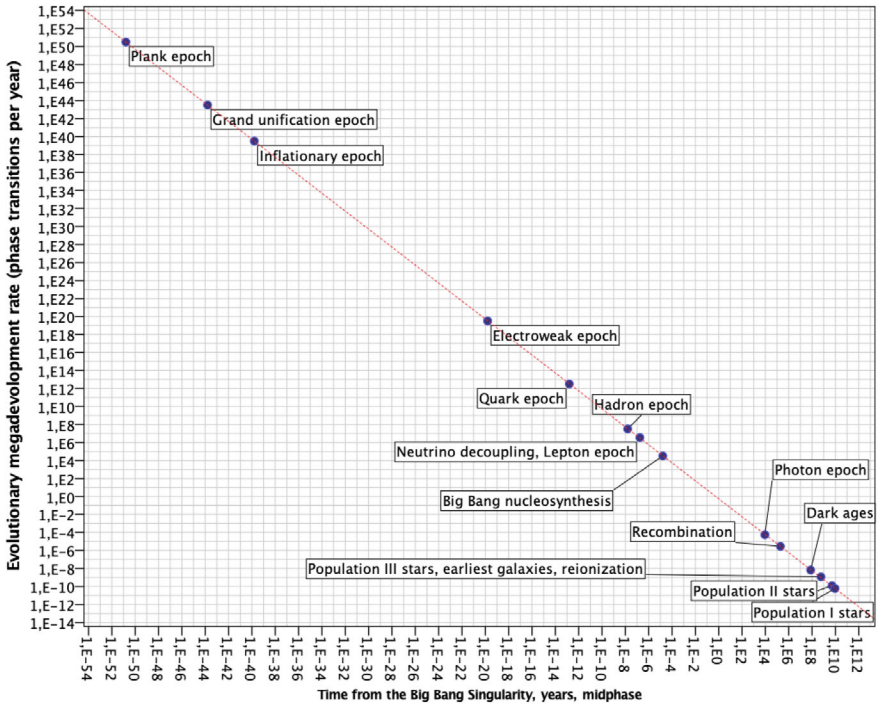

Fig. 10 Correlation between the time since the Big Bang Singularity and universal evolutionary megadevelopment rate (phase transitions per year). Scatterplot of the phases of the growth of complexity in the Universe, with the fitted power-law regression line **(log–log scale)**

the same factor of increased time until the next event. This plot is shown in Fig. 11, where the 10 events give an R-Square of 0.97 (in log transformed data) with a best fit of 7.6 decades for the time scaling factor (i.e., 4×10^7).

A factor of about 6 decades in time would be expected if the energy scaled by 1000 (due to the relationship of temperature and time after the Big Bang Singularity [see below]). A factor of 1000 in energy phenomena is seen in the middle range of physics phenomena from the proton mass 1000 MeV, the electron pair production mass and typical nuclear excitation energy of 1 MeV, the ionization energy of elements at around 1 keV, a chemical binding energy around 1 eV, and intermolecular binding energies in the meV range (room temperature e = 25 meV). While this range of energy scales allows for separation of phenomena by temperature, it is not fundamentally known why it is that way.

Thus, our analysis has demonstrated that the decelerating universal (cosmic) evolutionary development evidenced in the Universe for a few billions of years since the Big Bang Singularity can be very accurately described by the following equation:

$$y_t = \frac{C_2}{t - t^*}, \tag{13}$$

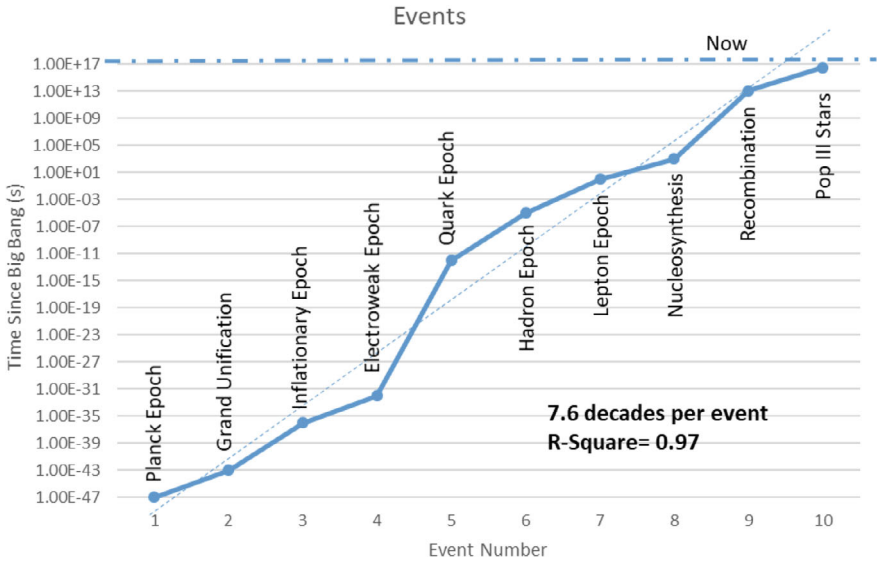

Fig. 11 Geometric sequence of post-Big-Singularity complexity jumps

where y_t is the rate of the universal complexity growth (complexity jumps per a unit of time) at time t; t^* is the time of the Bing Bang singularity, and C_2 is a constant.

Compare now this decelerating pattern of the universal (cosmic) evolutionary development evidenced in the Universe for a few billions of years since the Big Bang Singularity with the accelerating pattern of complexity growth traced on our planet for four billion years since the emergence of life on the Earth detected in the series of Modis–Kurzweil and Panov (see Fig. 12 and Table 3).

This comparison may be also summarized in Table 4.

It is difficult not to see here a striking symmetry—the basic regularities of the hyperbolic deceleration of the post-Big Bang universal increase in complexity turn out to be strikingly similar to the ones of the hyperbolic acceleration of the complexity growth observed on our planet for 4 billion years until the early 1970s.

3.1 Relationship Between the Cosmic Radiation Energy and Universal Complexity Growth Rate

The relationship between the cosmic radiation energy and universal complexity growth rate is displayed in Fig. 13.

Figure 14 is presented with direct order of values along the x-axis.

Thus, the relationship between radiation temperature (energy) of the Universe (eV) and universal complexity growth rate = evolutionary megadevelopment rate of the Universe (phase transitions per year) can be rather accurately ($R^2 = 0.99$)

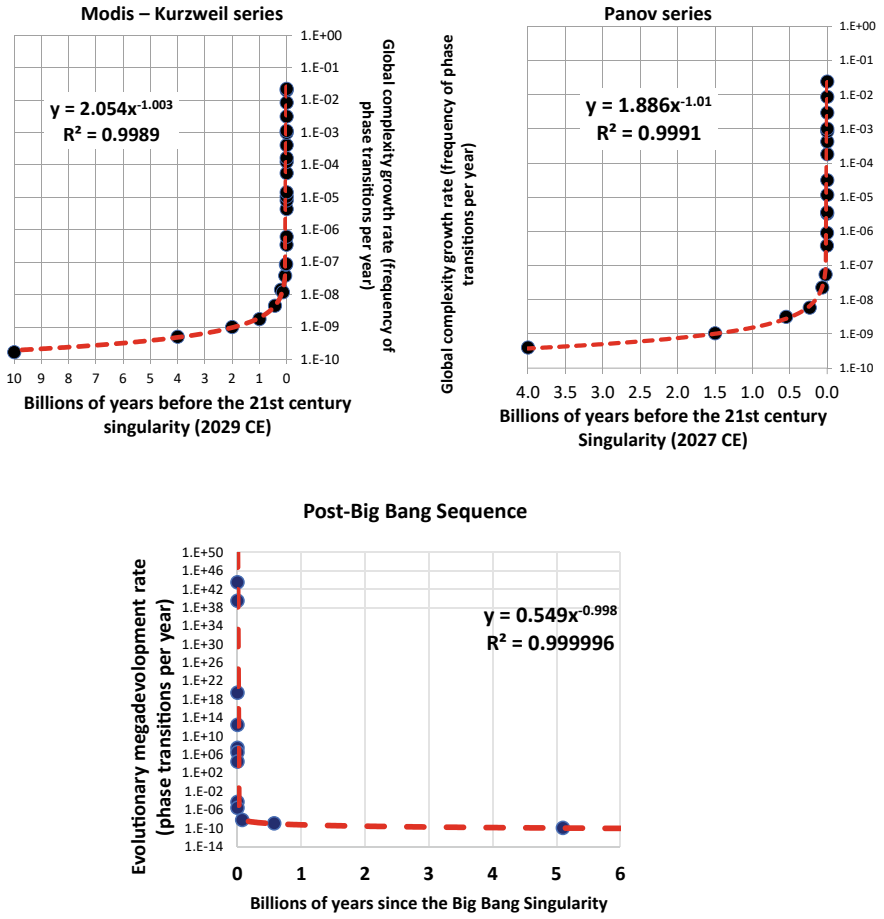

Fig. 12 Comparison of the decelerating pattern of the universal (cosmic) evolutionary development evidenced in the Universe for a few billions of years since the Big Bang Singularity (**16c** above) with the accelerating pattern of complexity growth traced on our planet for four billion years since the emergence of life on the Earth detected in the series of Modis–Kurzweil (**16a** above) and Panov (**16b** above)

described with the following equation:

$$y = 0.000003x^{1.95}, \text{ or } y = 0.000003E^{1.95}, \tag{14}$$

where y is the universal complexity growth rate (phase transitions per year) and $x = E$ is the radiation energy (temperature) of the Universe (eV).

Rounding 1.95 to 2 we obtain:

$$y = 0.000003E^2. \tag{15}$$

Table 3 Comparison of the decelerating pattern of the universal (cosmic) evolutionary development evidenced in the Universe for a few billions of years since the Big Bang Singularity with the accelerating pattern of complexity growth traced on our planet detected in the series of Modis–Kurzweil and Panov

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 twenty-first century Singularity ($t^* = 2029$); $x = t^* - t$; $y = \frac{2.054}{(t^*-t)^{1.003}}$; $y = \frac{2.054}{t^*-t}$; $\boldsymbol{y = \frac{C_1}{t^*-t}}$ $y = \frac{2.054}{2029-t}$.	$y = 1.886{*}x^{-1.01}$ ($R^2 = 0.9991$), where y is the rate of the global (planetary) complexity growth; x is the time till the twenty-first century Singularity ($t^* = 2027$); $x = t^*- t$; $y = \frac{1.886}{(t^*-t)^{1.01}}$; $y = \frac{1.886}{t^*-t}$; $\boldsymbol{y = \frac{C_1}{t^*-t}}$ $y = \frac{1.886}{2027-t}$.
Universal complexity growth deceleration pattern	
$y = 0.549{*}x^{-0.998}$ ($R^2 = 0.999996$), where y is the rate of the universal complexity growth; x is the time since the Big Bang Singularity ($t^* = 13.8$ biillion BP); $x = t - t^*$; $y = \frac{0.549}{(t-t^*)^{0.998}}$; $y = \frac{0.549}{t-t^*}$; $\boldsymbol{y = \frac{C_2}{t-t^*}}$ $y = \frac{0.549}{t-13.8\cdot10^9\text{BCE}}$	

Table 4 Comparison of the decelerating pattern of the universal (cosmic) evolutionary development with the accelerating pattern of complexity growth (version 2)

Decelerating universal (cosmic) evolutionary development	Accelerating global (biosocial) evolutionary development
$y = \frac{C_1}{t-t^*}$	$y = \frac{C_2}{t^*-t}$
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 since the Singularity rises by a factor of 3, the speed of the universal (cosmic) complexity growth lessens 3 times; if the time since 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

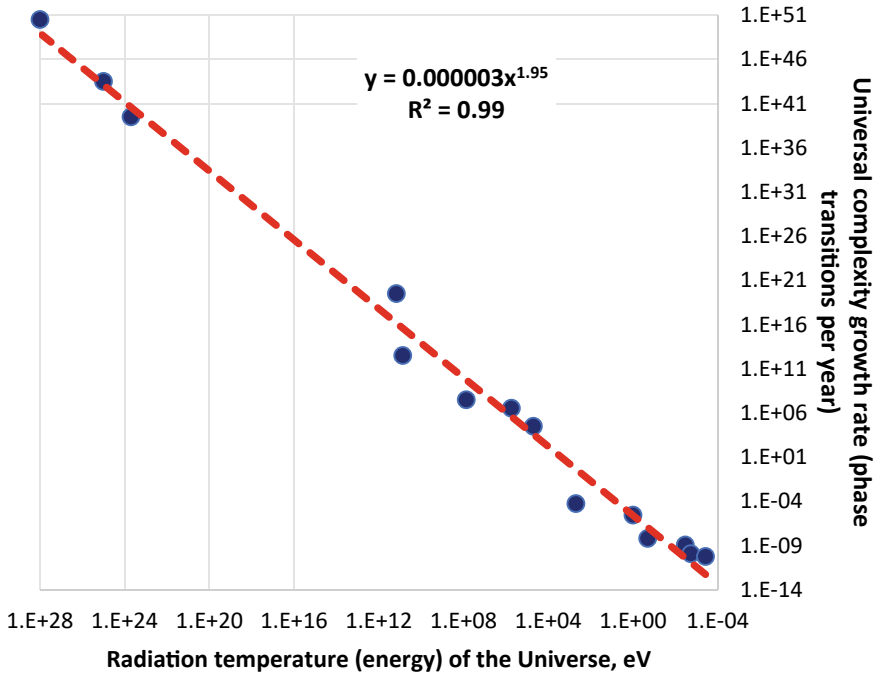

Fig. 13 Relationship between the radiation temperature (energy) of the Universe (eV) and universal complexity growth rate = evolutionary megadevelopment rate of the Universe (phase transitions per year). Scatterplot of the phases of the growth of complexity in the Universe, with the fitted regression line **(log–log scale, with reverse order of values along the x-axis)**

Thus, our analysis has demonstrated that the relationship between the radiation energy of the Universe and universal evolutionary megadevelopment rate can be very accurately described by the following equation:

$$y = \mathbf{C}_4 * E^2, \tag{16}$$

where y is the rate of the universal complexity growth (complexity jumps per a unit of time); E is the radiation energy of the Universe (eV), and C_4 is a constant.

Hence, in the cosmic history the rate of the universal complexity growth was proportional to the radiation energy of the Universe squared.

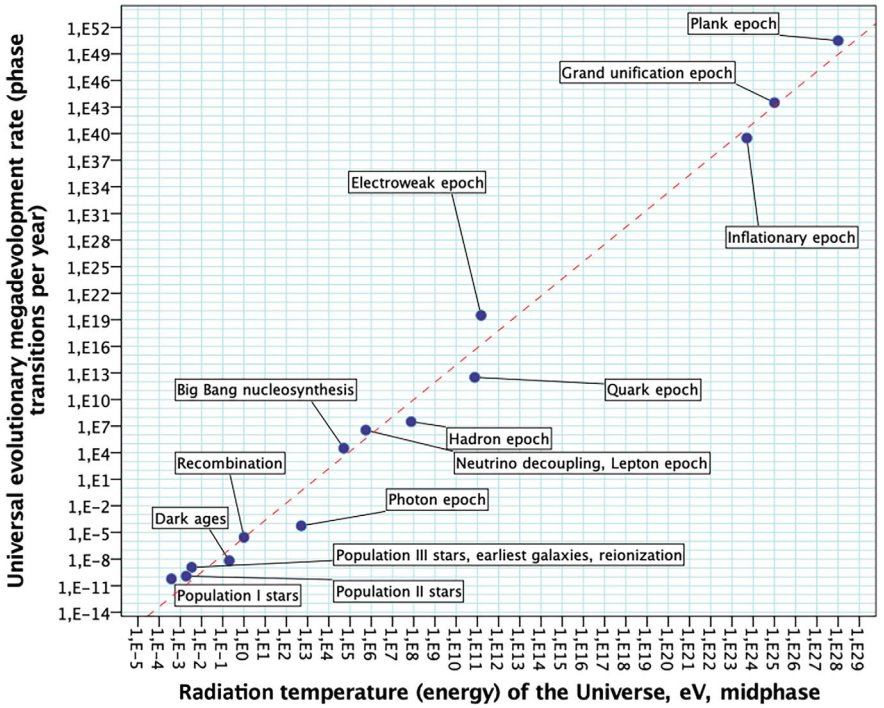

Fig. 14 Relationship between the radiation energy (temperature) of the Universe (eV) and universal evolutionary megadevelopment rate (phase transitions per year). Scatterplot of the phases of the growth of complexity in the Universe, with the fitted power-law regression line **(log–log scale, with direct order of values along the x-axis)**

3.2 Relationship Between Cosmic Radiation Energy and Time Since the Big Bang Singularity

It can be easily shown analytically that if within the cosmic evolution the rate of the universal complexity growth y equals constant C_1 divided by the time since the Big Bang Singularity ($t - t^*$, or x)

$$y = \frac{C_1}{t - t^*} \tag{13}$$

and the rate of the universal complexity growth y is proportional to the radiation energy of the Universe E squared

$$y = \mathrm{C}_4 * E^2 \tag{16}$$

then the radiation energy/temperature of the Universe E should be proportional to some constant C_3 ($= C_1/C_4$) divided by a square root of the time since the Big Bang

Singularity ($t - t^*$, or x):

$$\boldsymbol{E} = \frac{C_3}{\sqrt{\boldsymbol{t} - \boldsymbol{t}^*}} = C_3 x^{-0.5} = C_3 x^{-\frac{1}{2}} \tag{17}$$

Indeed, if $y = \frac{C_1}{t-t^*}$ and $y = C_4 E^2$, then $C_4 E^2 = \frac{C_1}{t-t^*}$. Thus, $E^2 = \frac{C_1}{C_4}\frac{1}{t-t^*}$. Hence, $E^2 = \frac{C}{t-t^*}$, where $C_3 = \frac{C_1}{C_4}$. So, finally we arrive at $E = \frac{C_3}{\sqrt{t-t^*}} = C_3 x^{-0.5} = C_3 x^{-\frac{1}{2}}$, where E is the radiation energy (temperature) of the Universe (eV), $x = t - t^*$ is time since the Big Bang Singularity and C_3 is a constant.

The analysis of the data presented above in Table 2 suggests that this is indeed the case. Our analysis has demonstrated that the relationship between time since the Big Bang Singularity (years) and radiation energy of the Universe (eV) can be quite accurately described by the following equation:

$$\boldsymbol{E} = \frac{C_3}{\sqrt{\boldsymbol{t} - \boldsymbol{t}^*}} = C_3 x^{-0.5} = C_3 x^{-\frac{1}{2}}, \tag{17}$$

where E is the radiation energy of the Universe (eV); x (or $t - t^*$) is the time since the Big Bang Singularity, and C_3 is a constant (see Figs. 15 and 16).

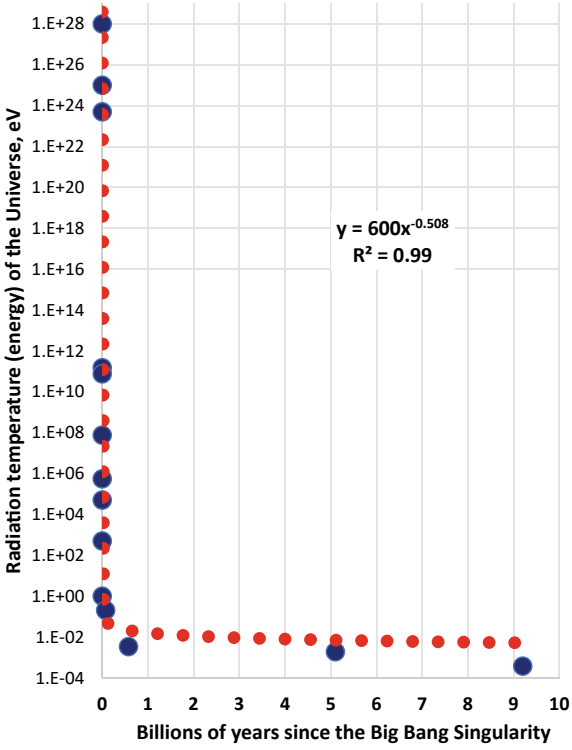

Fig. 15 Correlation between the time since the Big Bang Singularity (years) and radiation energy (temperature) of the Universe (eV). Scatterplot of the phases of the growth of complexity in the Universe, with the fitted power-law regression line **(with a logarithmic scale for the Y-axis)**

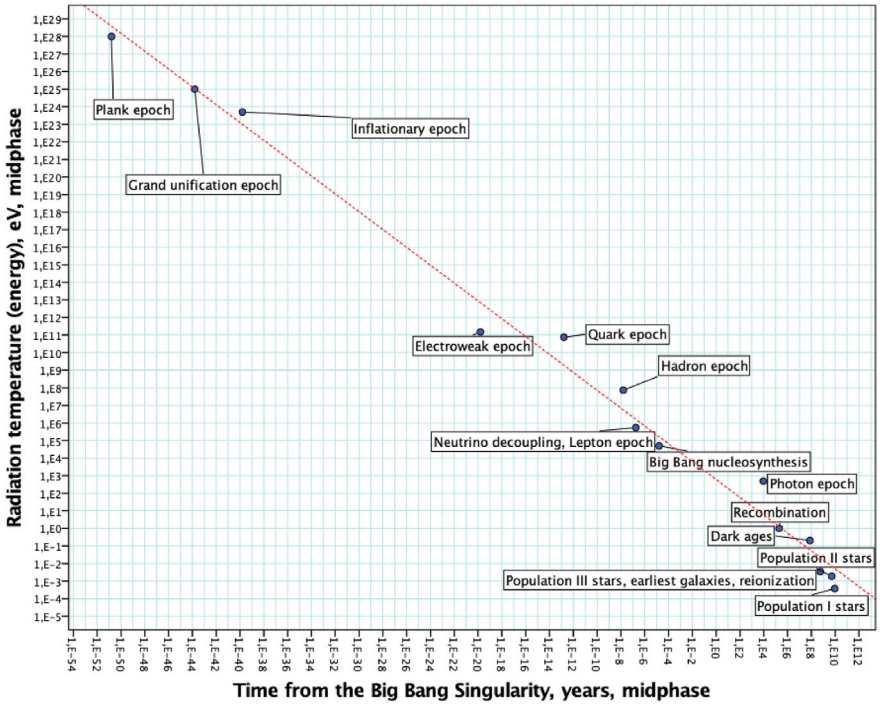

Fig. 16 Correlation between the time since the Big Bang Singularity (years) and radiation temperature (energy) of the Universe (eV). Scatterplot of the phases of the growth of complexity in the Universe, with the fitted power-law regression line **(log–log scale)**

In fact, this relationship is well known in cosmology and may be derived from original Friedman's equations (see, e.g., Mukhanov, 2005: 72).[8]

This suggests that the post-Big Bang hyperbolic deceleration of the universal complexity growth was directly connected with the post-Big Bang hyperbolic deceleration of the cooling of the Universe described by Eqs. (17) and (18).

[8] In fact, Eq. (13) describes quite accurately the relationship between the time since the Big Bang Singularity and the radiation energy (temperature) of the Universe for the radiation-dominated era of its history only, whereas for the matter-dominated era it is much better described by another equation (with −2/3 rather than −1/2 as the exponent):

$$E = C_3 x^{-\frac{2}{3}} \text{ (see, e.g., Mukhanov, 2005: 124).} \quad (18)$$

Note that this point explains why our mathematical analysis of the empirical estimates above (see Table 6 and Fig. 11) has produced a version of Eq. (14) with the exponent higher than 0.5. This is due to the fact that our analysis included a number of data points from the matter-dominated era. However, as the number of data points from the energy-dominated era exceeded the number of ones from the matter-dominated era, the value of the exponent turned out to be closer to 0.5 rather than 0.67.

Table 5 Summary general mathematical description of decelerating universal (cosmic) complexity growth

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

In fact, this suggests that the above detected hyperbolic pattern of deceleration of the post-Big-Bang universal complexity growth rate is not just an artefact of some dubious numerological exercise, but rather reflects a well-established scientifically pattern of the hyperbolical slowdown of the speed of the cooling of the Universe.

After the Big Bang Singularity, the growth of complexity in the Universe was very tightly connected with its cooling. It was this cooling that allowed the formation in the Universe of more and more complex entities—quarks, then hadrons, then atomic nuclei, then atoms, then molecules (see, e.g., Baumann, 2022; Gorbunov & Rubakov, 2018; Grinin, 2013; Hawking, 2009; LePoire, 2016; Mukhanov, 2005; Ryden, 2017). At the very beginning the cooling of the Universe proceeded very fast, and the complexity in the Universe grew extremely fast (with a few phase transitions just within the first second after the Big Bang Singularity). Then the cooling of the Universe slowed down, which caused the slowing down of the growth of complexity in the Universe.

As we have seen, the slowing down of the cooling of the Universe followed a hyperbolic pattern, and it does not appear to be of any surprise that the hyperbolic slowdown of the cooling of the Universe after the Big Bang Singularity caused a hyperbolic slowdown of the universal complexity growth rate.[9]

Table 5 summarizes the general mathematical description of decelerating universal (cosmic) evolutionary development.

4 Relationship Between Energy and Complexity Growth Rate in Global Development

Consider now the relationship between time till the twenty-first century singularity (years) and world energy production (TWy) estimated by John Holdren (1991; see Fig. 17).

[9] But it may well be said the other way around: at the beginning the concentration of the energy in the Universe was extremely high, which resulted in the extremely high rate of complexity growth, whereas the subsequent hyperbolic decline of the universal energy concentration resulted in the hyperbolic decrease of the rate of the growth of complexity in the post-Big-Bang Universe (e.g., LePoire, 2016: 229–230).

Table 6 General mathematical comparison between decelerating universal (cosmic) complexity growth and accelerating global (biosocial) complexity growth

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

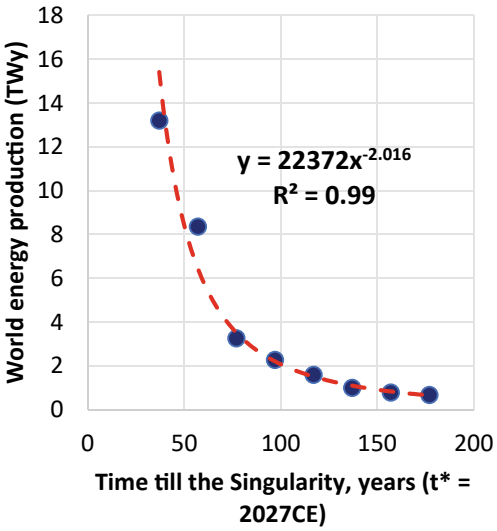

Fig. 17 Relationship between the time till the Singularity, years (t* = 2027 CE) and the world energy production (TWy). *Data source* Holdren (1991: 245)

As we see, for the pattern of global hyperbolic acceleration we find a quadratic relationship between the energy production and the time till the singularity inversed to the one we saw with respect to the post-Big-Bang universal deceleration:

$$E = \frac{C_6}{(t^* - t)^2}, \tag{19}$$

where E is the world energy production, $t^* - t$ is the time till the Singularity, and C_6 is a constant.

Correspondingly, the relationship between world energy production (E, TWy) and global complexity growth rate (y, phase transitions per year) is described by the following equation:

$$y = C_5\sqrt{E} \tag{20}$$

Thus, the growth of the world energy production 4 times only leads to a twofold increase in the global complexity growth rate; whereas in order for the global complexity growth to increase 4 times, the world energy production should grow by a factor of 16.

Note that this pattern is symmetrically opposite to the one we confronted above dealing with the post-Big-Bang deceleration of the universal complexity growth (see Eq. 12), when the decrease of the universal radiation energy 4 times led to the decrease of universal complexity growth rate by a factor of 16.

5 A General Comparison of Cosmic Deceleration and Global Acceleration

A general mathematical comparison between decelerating universal (cosmic) evolutionary development and accelerating global (biosocial) evolutionary development is presented below at Table 6.

As we see, the correlations between energy and decelerating growth of universal complexity display a striking inversed symmetry in comparison with accelerating global evolutionary development.

In the cosmic history, the rate of the universal complexity growth was proportional to the radiation energy of the Universe squared. In the global history, the rate of the global complexity growth was proportional to the square root of the world energy production (see Table 6, Row 2).

In the cosmic history, the moving from the Big Bang Singularity (Singularity_1) by n times was accompanied by the decrease of the radiation energy of the Universe by $\sqrt{n}$ times. Thus, the increase in the time since Singularity_1 by a factor of 4 was associated with the drop in the radiation energy of the Universe by a factor of 2. On the other hand, in the global history the moving toward the twenty-first century

Singularity (Singularity$_2$) by n times was associated with growth of the world energy production by n^2 times. Thus, the decrease in the time till Singularity$_2$ by a factor of 4 was associated with the increase in the world energy production by a factor of 16 (see Table 6, Row 2).

Finally, Row 1 of Table 6 demonstrates a perfect symmetry already discussed above: (1) the rate of the universal (cosmic) complexity growth decreases when we move from Singularity$_1$, whereas the rate of the global complexity growth increases when we approach Singularity$_2$; (2) more specifically, as the time since Singularity$_1$ increases n times, the universal (cosmic) complexity growth rate decreases the same n times, whereas when the time till Singularity$_2$ decreases n times, the global complexity growth rate increases the same n times; (3) even more specifically, if the time since Singularity$_1$ rises by a factor of 3, the speed of the universal (cosmic) complexity growth lessens 3 times; if the time since Singularity$_1$ increases 10 times, the universal (cosmic) complexity growth rate diminishes by a factor of 10, and so on. On the other hand, if the time till Singularity$_2$ lessens by a factor of 3, the speed of the global complexity growth rises 3 times; if the time till Singularity$_2$ diminishes 10 times, the global complexity growth rate escalates by a factor of 10, and so on.

6 Big History Periodization on the Basis of the Complexity Growth Patterns

Of course, this chapter poses more questions than it answers. The most important of those questions seems to be—why do the basic regularities of the hyperbolic deceleration of the post-Big Bang universal increase in complexity turn out to be so strikingly similar to the ones of the global hyperbolic acceleration of the complexity growth when their mechanisms seem to be so different?

On the one hand, it has been shown that the global hyperbolic acceleration pattern of the last 4 billion years appears to have been produced endogenously by the second order positive feedback between the complexity of the global sociobiological system and the rate of its complexity growth: the more complex the global biosocial system, the less time it takes it to make the next complexity jump—thus, the more complex the global system was, the faster its complexity grew. It has been shown that when written mathematically, such a feedback produces precisely a hyperbolic acceleration effect (see, e.g., Grinin et al., 2013; Korotayev, 2005, 2006a, 2006b, 2007, 2013, 2018, 2020b; Korotayev & Khaltourina, 2006; Korotayev & Malkov, 2012, 2016; Korotayev & Markov, 2014, 2015; Korotayev et al., 2006a, 2006b, 2015, 2016; Kremer, 1993; Kurzweil, 2001; LePoire, 2014, 2015a, 2015b, 2016, 2020a, 2020b; Markov & Korotayev, 2007, 2008; Taagepera, 1976, 1979; Tsirel, 2004; von Foerster et al., 1960).

On the other hand, as we have seen above, the hyperbolic deceleration of the post-Big-Bang universal complexity growth rate appears to have been produced exogenously by the post-Big-Bang hyperbolic deceleration of the cooling of the

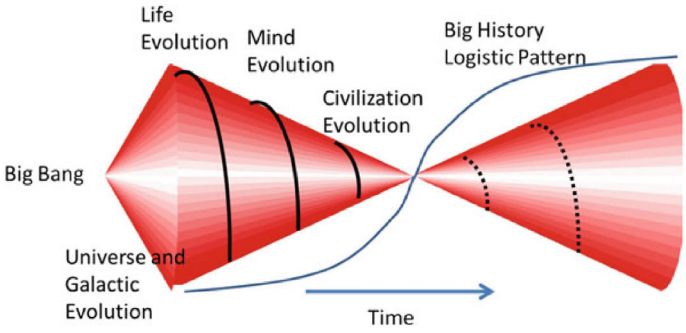

Fig. 18 Patterning of the Big History suggested earlier by David LePoire (2020a: 89)

Universe: the slower this cooling proceeded, the slower the universal complexity grew—thus, the post-Big-Bang hyperbolic deceleration of the cooling of the Universe resulted in the hyperbolic deceleration of the post-Big-Bang universal complexity growth rate.

Yet, those apparently so different mechanisms appear to have produced such strikingly similar patterns of hyperbolic deceleration / acceleration.

Of course, this point needs further investigations.

Note that that the quantitative analysis of the complexity growth patterns in the Big History that we have performed suggests the identification of the following eons[10] of the Big History:

1. eon of the hyperbolic deceleration of the universal complexity growth (from the Big Bang Singularity till 4 billion YBP);
2. eon of the hyperbolic acceleration of the global complexity growth (from 4 billion YBP till the early 1970s);
3. eon of the hyperbolic (?) deceleration of the global complexity growth (from the early 1970s till ?).

Note that this periodization is very congruent with the patterning of the Big History suggested earlier by David LePoire (2016, 2020a, 2020b) (see Fig. 18).

LePoire provides the following rather useful explication to a similar figure published in an earlier work of his (LePoire, 2016: 231):

> The Big Bang is on the left with time flowing to the right. The height of the curve represents the time between important events (that is, inversely proportional to the rate of change or

[10] We find it appropriate to follow the Big History period typology suggested by Robert Aunger on the basis of the typology used by geologists who "have divided earth history into eons (e.g., the Precambrian), eras (e.g., Paleozoic), periods (e.g., Cambrian) and epochs (e.g., Pleistocene), each a subcategory of the previous, based on changes in Earth's own composition and largescale changes in the biota inhabiting the planet's surface" (Aunger, 2007: 1165). Following this logic, he divides the Big History into two eons, with eons subdivided into eras, and eras subdivided into periods (Aunger, 2007; see also Chapter "Combining Evolutionary Complexity Indicators for Quantitative Comparison" [Aunger, 2025] this volume). Thus, eons occupy the highest level in Aunger's Big History periodization hierarchy.

> complexity increase) as the universe develops, at first slowing down from the Big Bang and then accelerating from life evolution, human evolution, and civilization development. The present would be close to the midpoint where the two cones meet. This would indicate the highest rate of change, that is, when an inflection occurs in the progress represented in the logistic pattern.

Our analyses have confirmed the veracity of such a periodization, identifying more rigorously the complexity growth patterns that are characteristic of the respective Big History eons.

It is easy to see that the first cone of LePoire corresponds to our first eon, the eon of the hyperbolic deceleration of the universal complexity growth. On the other hand, it corresponds to Erich Jantsch (1980: 77–96) Cosmic Prelude as well as to Aunger's "Cosmological Eon"[11] (Aunger, 2007: 1171), which Aunger explicitly additionally calls "decelerating" (Aunger, 2007: 1164). Thus, in this respect, the Big History periodization suggested by us correlates very well with the one proposed by Aunger. However, it adds some nuance to it, identifying the first Big History eon as **the eon of hyperbolically decelerating growth of the universal complexity**.

Aunger identifies only one era ("Material") within the first Big History eon. As our Big History periodization is based on complexity growth patterns criteria, we would suggest to identify within the first eon at least two eras:

1. Early Universe Era (from the Big Bang Singularity/BBS up to the end of the Cosmological Dark Ages around 150 mln years after the BBS).
2. Stelliferous Era (since the end of the Cosmological Dark Ages around 150 mln years after the BBS).[12]

This two eras appear to be clearly distinguished by the principal drivers of the universal complexity growth. Within the Early Universe Era (as has been mentioned above) the growth of complexity was very tightly connected with its cooling. It was this cooling that allowed the formation in the Universe of more and more complex entities—quarks, then hadrons, then atomic nuclei, then atoms, then molecules. At the very beginning the cooling of the Universe proceeded very fast, and the complexity in the Universe grew extremely fast (with a few phase transitions just within the first second after the Big Bang Singularity). Then the cooling of the Universe slowed down, which caused the slowing down of the growth of complexity in the Universe.

However, around 150 million years after the Big Bang, with the end of the cosmological Dark Ages and the start of the Stelliferous Era, the further cooling of the Universe stopped playing any significant role in the further growth of the universal

[11] It also corresponds to the "Matter Cone" of Gregg Henriques (2003, 2011; Henriques et al., 2019) and to the "Realm of Physical Law" of Tyler Volk (2017, 2020; see also Henriques & Volk, 2023 and Chapter "Integrating the Tree of Knowledge and Combogenesis Approaches to Big History" [Volk & Henriques, 2025] in this volume), as well as to "Physical Evolution" of Nicholas Hoggard (2024, see also Chapter "A New Theory of Evolution is Supported by the Teaching Patterns of Human Ancestors" [Hoggard, 2025] in this volume).

[12] It more or less corresponds to the Grinin's (2019) Big History "Star-Galaxy Era", or the Grinins' Big History "Stellar-Cosmic Phase"—see Chapter "Big History Evolutionary Phases" (Grinin & Grinin, 2025) in this volume; see also Grinin and Grinin (2023).

complexity. Against this background, a new driver of the universal complexity growth emerged. There are some grounds to maintain that this was the nucleosynthesis in the emerging stars that produced elements more complex than hydrogen and helium that appeared in the Epoch of Big Bang Nucleosynthesis (between 10 and 1000 s after the BBS). We will not go here in any more details, as this theme is a subject of special study in an another paper of ours (Korotayev & LePoire, 2025).

In fact, the phases of the universal complexity growth identified above in Table 2 can well be regarded as the further level of periodization of the first Big History eon. Following conventions of geologists, Aunger subdivides eras into periods. However, I would prefer to denote the subdivisions of the Early Universe Era "epochs" as the denominations of most those subdivisions as "epochs" (Planck Epoch, Grand Unification Epoch, Electroweak Epoch, Quark Epoch, Hadron Epoch, Lepton Epoch, Photon Epoch) appears to be rather well established by the moment (see, e.g., Brandenburg et al., 2017; Gustafson, 2020; Holmes, 2023; Meyer-Ortmanns & Thurner, 2011; Muratov et al., 2013; Perrone et al., 2021; Yang & Rafelski, 2022). Then, for the sake of uniformity, I will subdivide all the Big History eras in epochs, rather than periods.

All this yields the following periodization of the first Big History eon (see Table 7).

Within the proposed approach, the second Big History eon is denoted as the "Eon of the Hyperbolic Acceleration of the Global Complexity Growth".[13] It corresponds almost entirely to the "Terrestrial Eon" identified by Aunger (2007). Robert Aunger subdivides this eon into three eras: (1) Biological, (2) Cultural, and (3) Technological. This more or less corresponds to the subdivision by David LePoire of his "second cone"/eon into (1) the Era of Life Evolution, (2) the Era of Mind Evolution, and (3) the Era of Civilization Evolution (LePoire, 2014, 2015a, 2015b, 2016, 2020a, 2020b), to Gregg Henriques' "Cones" of (1) Life, (2) Mind, and (3) Culture (Henriques, 2003, 2011; Henriques & Volk, 2023; Henriques et al., 2019; see also Chapter "Integrating the Tree of Knowledge and Combogenesis Approaches to Big History" [Volk & Henriques, 2025] in this volume), as well as to eras of Biological, Cultural, and Information Technology Evolution identified by Nicholas Hoggard (2024, see also Chapter "A New Theory of Evolution is Supported by the Teaching Patterns of Human Ancestors" [Hoggard, 2025] in this volume).

On the other hand, Tyler Volk and the Grinins find here only two main "eras". Tyler Volk calls them (1) "Realm of Biological Evolution", and (2) "Realm of Cultural Evolution" (Volk, 2017, 2020; see also Henriques & Volk, 2023 and Chapter "Integrating the Tree of Knowledge and Combogenesis Approaches to Big History" [Volk & Henriques, 2025] in this volume). The Grinins denote them as (1) "Biological Main Evolutionary Phase of Big History" and (2) "Social Main Evolutionary Phase of Big History" (see Chapter "Big History Periodization. Complexity, Directions and Phase Characteristics" [Grinin & Grinin, 2025] in this volume; see also Grinin & Grinin, 2023).

[13] However, one may wonder whether it would not make sense to add an intermediate eon of life formation—as its pattern does not appear to follow either the pattern of hyperbolic deceleration of the first eon or the hyperbolic acceleration of the second.

Table 7 Periodization of the first eon of the Big History, the Eon of Hyperbolically Decelerating Growth of the Universal Complexity

Eon	Date of the start (seconds/ years after the BBS*)	Era	Date of the start (seconds/ years after the BBS*)	Epoch	Date of the start (seconds/years after the BBS*)
Eon of Hyperbolically Decelerating Growth of the Universal Complexity ("Universal Deeceleration Eon")	0	Early Universe Era	0	Planck Epoch	0
				Grand Unification Epoch	10^{-43} s
				Inflationary Epoch	10^{-36} s
				Electroweak Epoch	10^{-32} s
				Quark Epoch	10^{-12} (one trillionth of a second)
				Hadron Epoch	10^{-05} (0.00001, 10 millionths of a second)
				Lepton Epoch	1 s since the Big Bang Singularity
				Big Bang Nucleosynthesis Epoch	10 s
				Photon Epoch	1000 s
				Recombination Epoch	$1.8*10^4$ (18 thousand years)
				Cosmological Dark Ages	370 thousand years since the B. Bang Singularity
		Stelliferous Era	150 million years after the BBS*	Population III Stars Era, earliest galaxies, reionization	150 million years

(continued)

Table 7 (continued)

Eon	Date of the start (seconds/ years after the BBS*)	Era	Date of the start (seconds/ years after the BBS*)	Epoch	Date of the start (seconds/years after the BBS*)
				Population II Stars Era, first generation III stars appear against the background of predominance of generation II stars, medium complexity galaxies, primitive planets, primitive chemical evolution	1 billion years after the BBS*
				Population I Stars Era, predominance of population I stars, complex galaxies, complex planets, complex chemical evolution	9.2 billion years after the BBS* (4.6 billion years BP). Alternatively—beginning about 10 billion years BP (about 4 billion years after the BBS)

* = Big Bang Singularity

In fact, within our Big History periodization on the basis of the complexity growth patterns, the Big History second eon, the Eon of Hyperbolically Accelerating Growth of the Global Complexity, can be reasonably subdivided both in two and three eras. On the one hand, its subdivision into (1) the Era of Hyperbolically Accelerating Growth of Biological Complexity and (2) the Era of Hyperbolically Accelerating Growth of Sociocultural Complexity appears most logical, as the growth of global complexity was driven during the first era mostly by the mechanisms of biological evolution; during the second era this was mostly done by the mechanisms of sociocultural evolution,[14] whereas it has been shown that though mechanisms of both types of evolution possess significant similarities, the differences between them are very

[14] In fact, biological evolution of humans continues up to now. What is more, it appears to have even accelerated in the last 10,000 years, after the Neolithic Revolution (see, e.g., Cochran & Harpending,

substantial indeed (Grinin et al., 2009, 2011a, 2011b, 2013, 2014, 2015; Korotayev & Markov, 2015; Markov & Korotayev, 2007, 2008; Markov et al., 2010), which by itself justifies the subdivision of the second eon into the two respective eras.

On the other hand, at the conjunction of the Era of Hyperbolically Accelerating Growth of Biological Complexity and the Era of Hyperbolically Accelerating Growth of Sociocultural Complexity (for the period stretching from the onset of human evolution/"anthropogenesis" a few million years BP up to the Upper Paleolithic Revolution about 50 thousand years BP) we can identify an intermediate era when the growth of complexity was achieved both through biological evolution (without which, e.g., the radical increase in the brain complexity among the hominins/hominini would be impossible) and through sociocultural evolution (without which we would not see, e.g., an impressive development of stone industries, or domestication of fire). During this era, biological evolution and sociocultural evolution appear to have contributed more or less equally to the growth of complexity, being tightly interwoven and constituting a single process of gene-culture coevolution (though, with the passage of time, the comparative contribution of biological evolution to the complexity growth tended to decrease, and the one of sociocultural evolution tended to increase).

This part of the second Big History eon can be denoted as an intermediate Era of Hyperbolically Accelerating Growth of Biosocial Complexity. It more or less corresponds to the second era of the second Big History eon identified by Aunger, LePoire and Henriques. But especially well does it correspond to the Grinins' "Biosocial Intermediate Phase of Big History" (see Chapter "Big History Periodization. Complexity, Directions and Phase Characteristics" [Grinin & Grinin, 2025] in this volume; see also Grinin & Grinin, 2023).

Above, we have tried to detect the general pattern of the acceleration of the global complexity growth using two time series—Panov and Modis–Kurzweil (see also Korotayev, 2018, 2020a, 2020b, 2024). LePoire (2020a, 2020b) finds the Panov series more reliable, so let use it[15] to sketch the possible subdivision of the 2nd eon eras into epochs (corresponding to major biosocial complexity jumps within those eras, see Table 8).

The suggested subdivision of three eras of the Big History Eon of Global Acceleration into epochs more or less corresponds to such a subdivision proposed within Big History periodizations advanced by Aunger, Volk and LePoire, as well as Grinin's periodization of its last era.[16]

2009). However, after the Upper Paleolithic Revolution (about 50,000 YBP) it does not appear to have contributed to the growth of global complexity in any noticeable way.

[15] With some amendments/clarifications for names and dates of epochs on the basis of more recent data.

[16] In all the periodizations we find two epochs (corresponding mostly to prokaryotic cells [1] and eukaryotic cells [2]) between the emergence of life on the Earth and the Cambrian E xplosion (though Aunger starts the third period/epoch of the second BH eon somehow earlier than the Cambrian Explosion). On the other hand, Aunger and Volk identify only one period/epoch between the Cambrian Explosion and the onset of anthropogenesis (they both denote it as the one of "Multicellular Organisms"), whereas LePoire and I (after Panov) find here three epochs.

Table 8 Periodization of the second eon of the Big History, the Eon of Hyperbolically Accelerating Growth of the Global Complexity

Eon	Date (and event) of the start (years before present/ BP)	Era	Date (and event) of the start (years before present [BP])	Epoch	Date (and event ~ "complexity jump") of the start (years before present [BP]/CE)
Eon of Hyperbolically Accelerating Growth of the Global Complexity ("Global Acceleration Eon")	*c*. 4 billion BP (emergence of life on the Earth)	Era of Hyperbolically Accelerating Growth of Biological Complexity ("Biological Era")	*c*. 4 billion BP (emergence of life on the Earth)	Early Life Epoch (1)	*c*. 4 billion BP (emergence of life on the Earth)
				"Neoproterozoic" Epoch[17] (2)	*c*. 1.5 billion BP (Panov's "Neoproterozoic Revolution/Oxygen crisis")
				Paleozoic (3)	*c*. 540 million BP (Cambrian Explosion)
				Mesozoic (4)	*c*. 252 million BP (Panov's "Reptiles Revolution")
				Cenozoic (5)	*c*. 66 million BP (Panov's "Mammalia Revolution")
				Neogene (6)	*c*. 23 million BP (Panov's "Hominoid Revolution", "A big evolution explosion of Hominoidae")

(continued)

[17] Starts significantly earlier than the Neoproterozoic Era identified by paleontologists/geologists.

Table 8 (continued)

Eon	Date (and event) of the start (years before present/ BP)	Era	Date (and event) of the start (years before present [BP])	Epoch	Date (and event ~ "complexity jump") of the start (years before present [BP]/CE)
		Intermediate Era of Hyperbolically Accelerating Growth of Biosocial Complexity ("Biosocial Era")	*c.* 6 million BP (separation of Australopithecine from Pan genus)	Anthropogene Epoch (7)	*c.* 6 million BP (separation of Australopithecine from Pan genus)
				Earlier Lower Paleolithic (8)	*c.* 3.3 million BP (Panov's "Paleolithic Revolution", emergence of the first stone industries)
				Later Lower Paleolithic (9)	*c.* 700,000 BP (domestication of fire, proliferation of archaic humans, transition to Late Acheulean stone industries)
				Middle Paleolithic (10)	*c.* 300,000 BP (emergence of anatomically modern humans, prepared-core technique, composite tools, rudimentary forms of artistic expression)

(continued)

Table 8 (continued)

Eon	Date (and event) of the start (years before present/ BP)	Era	Date (and event) of the start (years before present [BP])	Epoch	Date (and event ~ "complexity jump") of the start (years before present [BP]/CE)
		Era of Hyperbolically Accelerating Growth of Sociocultural Complexity ("Sicioculturalera")	*c.* 50,000 BP (Upper Paleolithic Revolution)	Upper Paleolithic (11)	*c.* 50,000 BP (Upper Paleolithic Revolution)
				Early (Pre-Civilization) Agrarian Epoch (12)	*c.* 12,000–9,000 BP (Neolithic Revolution)
				Epoch of Early Agrarian Civilizations (13)	*c.* 4000–3000 BCE (Urban Revolution)
				Epoch of Advanced Agrarian Civilizations (14)	*c.* 800–500 BCE (Axial Age Revolutions)
				Early Modern Epoch (15)	*c.* 1450–1550 CE (Panov's "First Industrial Revolution", "emergence of manufacture, printing of books", "culture revolution" + Gunpowder Revolution in the state building, and so on and so forth)

(continued)

Table 8 (continued)

Eon	Date (and event) of the start (years before present/ BP)	Era	Date (and event) of the start (years before present [BP])	Epoch	Date (and event ~ "complexity jump") of the start (years before present [BP]/CE)
				Industrial Epoch (16)	*c.* 1830–1840 (Panov's "Second Industrial Revolution")
				Postindustrial Epoch (17)	*c.* 1950 (Panov's "Information Revolution")

Notes 1. Panov (2005) identifies a "phase transition" around 400,000 BP, supplying this with the following description: "9. The beginning of Acheulean period – **$0.4 \cdot 10^6$ years ago**. Standardized symmetric stone implements" (p. 221). For me, this description now does not make much sense, since, according to the current knowledge, the Acheulean archaeological industry of stone tool manufacture emerged more than one million years before the date indicated by Panov (see, e.g., Asfaw et al., 1992; Lepre et al., 2011; Mussi et al., 2023; Pappu et al., 2011; Roche et al., 2003). In general, I do not see any evidence for any "complexity jump" around the date indicated by Panov; thus, I had to omit it from the periodization above

2. Panov (2005), LePoire (2016), as well as Modis (2002, 2003) and Kurzweil (2005) find a phase transition/"complexity jump" in the mid-first century CE. This does not appear to be supported by any empirical evidence that rather suggests a certain decline in global complexity between 150 and 600 CE (e.g., Zinkina et al., 2019). Hence, I had to omit the respective phase transition and corresponding phase/epoch from my Big History periodization.[18] If one can find anything like a "complexity jump" between 150 and 1450 CE, it would be rather the eleventh century when one could see a simultaneous significant increase in complexity in most of the World System centers of that time (e.g., Zinkina et al., 2019); the last point, however, can hardly be regarded as widely recognized yet

[18] Its presence in the schemes of Panov, LePoire, Modis, and Kurzweil seems to be accounted for by the fact that European historiography used to traditionally identify the demise of the Western Roman Empire in 476 CE as a conventional landmark indicating the end of Antiquity and the start of Middle Ages.

The Big History periodizations suggested by LePoire and me identify one more eon (in comparison with Aunger's periodization)—the Eon of Hyperbolically (?) Decelerating Growth of the Global Complexity ("Global Deceleration Eon"). There are grounds to maintain that the transition to this Eon began in the early 1970s

Within Aunger's (2007) periodization, the period between 25 million and 2.5 million BP is classified as a part of "Cultural Era" (roughly corresponding to our "Biosocial Era"), whereas according to our classification most of this period falls into the previous era (which both Aunger and I call "Biological") and the Biosocial Era only starts *c.* 6 million BP with separation of Australopithecine from Pan genus. In general, Augen's "Tool Period" would roughly correspond to our Earlier Lower Paleolithic Epoch, the "Fire Period" would mostly match the Later Lower Paleolithic, and the "Multi-Tool Period" would parallel the Middle Paleolithic. Aunger's "Complex Tool Period" (directly preceding the "Agriculture" one) would mostly correspond to our Upper Paleolithic. Aunger includes both "Complex Tool Period" and "Agriculture Period" into the second era of the second Big History eon, whereas we are definitely in favor of their inclusion into the third era that we denote as "Sociocultural Era". Aunger's "Agriculture Period" corresponds to three epochs of our periodization—Early Agrarian (Pre-Civilization) Epoch (12), Epoch of Early Agrarian Civilizations (13), and Epoch of Advanced Agrarian Civilizations (14), though the last centuries of the last epoch fall into Aunger's "Machine Period" that starts around 1000 CE (the last point seems to reflect a rather wide use of primitive machines, first of all watermills and windmills, in the most advanced agrarian societies). The other four Aunger periods ("Steam" (1), "Electric [telegraph/telephone]" (2), "[Internal Combustion] Engine" (3), and "Nuclear" (4)) more or less parallel three last epochs of our periodization (whereas our "Industrial Epoch" would include Eunger's periods (2) and (3)).

Within Volk's periodization, for the last 20 million years, "epochs" cover wider periods than in all the other periodizations. He identifies only one epoch ("Animal social groups") for the whole of the intermediate era of the others, whereas for the last 50,000 years he identifies only three epochs ("Tribal metagroups", "Agrovillages", and "Geopolitical states"). In the meantime, Aunger, LePoire, and I (partly with Panov) identify for this stretch of time 7 "periods"/"epochs".

There are still some differences between the subdivision of the second eon eras into epochs between LePoire's periodization and mine too. As has already been mentioned, I insist on identifying the landmark between the early and advanced agrarian civilizations as being in the mid-1st millennium BCE, rather than the mid-1st millennium CE, as the very significant increase in complexity of the agrarian civilizations (known as the "Axial Age Revolution") was observed in the mid-1st millennium BCE, and in no way around 500 CE. In addition, LePoire places his "Epoch of Early Humans" (corresponding to our Upper Paleolithic Epoch) and "Agriculture Epoch" (corresponding to our Early (Pre-Civilization) Agrarian Epoch) into the second era, whereas we place them in the third (this is accounted for first of all by the point that our bases for the subdivision of the second eon into eras are far from being identical). Otherwise, the epochs identified by LePoire almost perfectly correspond to the one identified by us (mostly after Panov). Indeed, his "Information Epoch" perfectly corresponds to our Postindustrial one; his "Industrial Epoch" perfectly matches ours not only by its dates but also by its name; his "Scientific/Exploration Epoch" clearly parallels our Early Modern one; his "Scientific/Exploration Epoch" quite corresponds to our Epoch of Advanced Agrarian Civilizations; LePoire's "Civilization Epoch" parallels our Epoch of Early Agrarian Civilizations; his "Ecoadaptation Epoch" (preceding the Upper Paleolithic Revolution) corresponds to our Middle Paleolithic one; his "Epoch of Fire" parallels our Later Paleolithic one—and so on.

Finally, our periodization of the last era well matches its periodization by Grinin (see, e.g., Grinin et al., 2020a, 2020b, 2024). Our Upper Paleolithic Epoch would almost perfectly correspond to his Hunter-Gatherer Production Principle; our Early (Pre-Civilization) Agrarian Epoch quite matches Phases 1–2 of his Craft-Agrarian Production Principle; our Epoch of Early Agrarian Civilizations clearly parallels its Phases 3–4, whereas our Epoch of Advanced Agrarian Civilizations matches its Phases 5–6; our Early Modern Epoch well corresponds to Phases 1–3 of his Industrial Production

(see, e.g., Khaltourina & Korotayev, 2007; Korotayev, 2018, 2020b; Korotayev & Bogevolnov, 2010; Korotayev et al., 2015, 2020).[19]

We are at the very start of this new Big History eon, so we only begin its study, and a little about this eon is known by now. Our study of the previous Big History eons only allows us to conclude that the hyperbolic acceleration of the global complexity growth cannot continue beyond the twenty-first century,[20] and thus, we are entering a new Big History eon when the hyperbolic acceleration pattern of the global complexity growth is bound to change to some other pattern. Our study of the previous Big History eons suggests that this is most likely to be a pattern of hyperbolic deceleration, but this point can hardly be regarded as confidently proven.[21]

And of course, it is too early to propose any subdivision of this new Big History eon into eras and epochs.[22] In fact, as the hyperbolic pattern of the global complexity growth within the Third Eon is still very likely, this would imply that its first epochs should be very short; and it cannot be excluded that the first epoch of this eon is already over, or is about to be over (it cannot be, for example, excluded that the transition to the second epoch of the Third Eon might be connected to the breakthrough in the development of the AI). Anyway, it is hardly likely that we would be able to identify with any confidence the nature and possible length of the two first epochs of the Third Big History Eon earlier than in a decade or two…

Finally, our overall Big History periodization on the basis of the complexity growth patterns and phases can be presented as follows (see Table 9).

Principle, our Industrial Epoch parallels its Phases 4–6, whereas our Postindustrial Epoch matches rather well Phase I of Grinin's Cybernetic Production Principle.

[19] Note that, according to alternative calculations of Grinin (see Grinin et al., 2020a, 2020b, 2024), the global complexity growth might temporarily return to the hyperbolic trajectory before its final transition to a new trajectory in the late twenty-first—early twenty-second century. However, even in this case it turns out that we are living in the period of transition from the Second to the Third Eon of the Big History, whereas a century difference does not appear significant indeed.

[20] LePoire (2013, 2014, 2015a, 2015b, 2016, 2020a, 2020b) and Korotayev (2018, 2020a, 2020b, 2024).

[21] Note that the third "decelerating" Big History eon proposed by David LePoire and me appears to be quite congruent with the vision of our futures suggested by Joseph Voros (2019), but does not appear to be as compatible with the one of Marc Widdowson (see Chapter "Last Stop on the Cosmic Journey: An Estimated Time of Arrival" [Widdowson, 2025] in this volume) who offers a much more optimistic vision of our future – implying a new era (or even eon?) of not even global, but rather universal hyperbolic complexity growth.

[22] In Table 9 a couple of dates are suggested most hypothetically on the assumption of a possible symmetry of the Second and Third eons, at least in the beginning of the Third Eon (which has been already implied by Modis [2002, 2003, 2020], LePoire [2016, 2020a, 2020b], and Grinchenko [2006; Grinchenko & Shchapova, 2010]).

Table 9 Overall Big History periodization on the basis of the complexity growth patterns and phases

Eon	Date of the start	Era	Date of the start	Epoch	Date of the start[23]
Eon of Hyperbolically Decelerating Growth of the Universal Complexity ("Universal Deceleration Eon")	0	Early Universe Era	0	Planck Epoch	0
				Grand Unification Epoch	10^{-43} s
				Inflationary Epoch	10^{-36} s
				Electroweak Epoch	10^{-32} s
				Quark Epoch	10^{-12} (one trillionth of a second)
				Hadron Epoch	10^{-05} (0.00001, 10 millionths of a second)
				Lepton Epoch	1 s since the Big Bang Singularity
				Big Bang Nucleosynthesis	10 s
				Photon Epoch	1000 s
				Recombination Epoch	18 thousand years
				Cosmological Dark Ages	370 thousand years
		Stelliferous Era	150 million years	Population III Stars Era, earliest galaxies	150 million years
				Population II Stars Era	1 billion years after the BBS

(continued)

[23] Seconds/years after the BBS for the First Eon; years before present [BP]/CE for the Second and the Third.

Table 9 (continued)

Eon	Date of the start	Era	Date of the start	Epoch	Date of the start
				Population I Stars Era	9.2 billion years after the BBS (4.6 billion years BP). Alternatively—beginning about 10 billion years BP (about 4 billion years after the BBS)
Eon of Hyperbolically Accelerating Growth of the Global Complexity ("Global Acceleration Eon")	*c*. 4 billion BP (emergence of life on the Earth)	Era of Hyperbolically Accelerating Growth of Biological Complexity ("Biological Era")	*c*. 4 billion BP (emergence of life on the Earth)	Early Life Epoch	*c*. 4 billion BP (emergence of life on the Earth)
				"Neoproterozoic" Epoch	*c*. 1.5 billion BP (Panov's "Neoproterozoic Revolution/ Oxygen crisis")
				Paleozoic	*c*. 540 million BP (Cambrian Explosion)
				Mesozoic	*c*. 252 million BP (Panov's "Reptiles Revolution")
				Cenozoic	*c*. 66 million BP (Panov's "Mammalia Revolution")
				Neogene	*c*. 23 million BP (Panov's "Hominoid Revolution")

(continued)

Table 9 (continued)

Eon	Date of the start	Era	Date of the start	Epoch	Date of the start
		"Biosocial Era"	*c.* 6 million BP (separation of Australopithecine from Pan genus)	Anthropogene Epoch	*c.* 6 million BP (separation of Australopithecine from Pan genus)
				Earlier Lower Paleolithic	*c.* 3.3 million BP (Panov's "Paleolithic Revolution", first stone industries)
				Later Lower Paleolithic	*c.* 700,000 BP (domestication of fire, proliferation of archaic humans, Late Acheulean stone industries)
				Middle Paleolithic	*c.* 300,000 BP (emergence of anatomically modern humans, composite tools etc.)
		Era of Hyperbolically Accelerating Growth of Sociocultural Complexity ("Sociocultural Era")	*c.* 50,000 BP (Upper Paleolithic Revolution)	Upper Paleolithic	*c.* 50,000 BP (Upper Paleolithic Revolution)
				Early (Pre-Civilization) Agrarian Epoch	*c.* 12,000–9000 BP (Neolithic Revolution)
				Epoch of Early Agrarian Civilizations	*c.* 4000–3000 BCE (Urban Revolution)
				Epoch of Advanced Agrarian Civilizations	*c.* 800–500 BCE (Axial Age Revolutions)
				Early Modern Epoch	*c.* 1450–1550 CE (Panov's "First Industrial Revolution")
				Industrial Epoch	*c.* 1830–1840 (Panov's "Second Industrial Revolution")

(continued)

Table 9 (continued)

Eon	Date of the start	Era	Date of the start	Epoch	Date of the start
				Postindustrial Epoch	*c.* 1950 (Panov's "Information Revolution")
The Third Eon[24]	*c.* the early 1970s–the late 1990s (?)	Era 1 (???)	early 1970s–1990s (?)	Epoch 3.1	*c.* the early 1970s–the late 1990s (?). Beginning of large inflection (i.e., no acceleration but still moving fast)
				Epoch 3.2	*c.* 2050 (?).Inflection: major transitions in energy, environment, demographics (aging), technology (Cyber)
				Epoch 3.3	*c.* 2150 (???). End of inflection to slowing down (deceleration). Adjustments to slower change
				???????	???????
		Era 2 (???)	???	???????	???????
				???????	???????

Note that, within the proposed periodization, the whole course of the Big History is subdivided into three eons identified on the basis of the complexity growth pattern that is characteristic for the respective eon; each eon is subdivided into eras identified on the basis of the complexity growth driver that was typical for the respective era; and, finally, each era is subdivided into epochs identified on the basis of the highest level of complexity achieved within the respective epoch (thus, the borders between epochs correspond to complexity jumps such as emergence of hadrons, recombination, Cambrian explosion, Upper Paleolithic Revolution, transition from foraging to food production and so on)

[24] Eon of Hyperbolically (?) Decelerating Growth Rate (?) of the Global Complexity ("Global Deceleration Eon").

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Andrey Korotayev heads the Center for Stability and Risk Analysis at the HSE University in Moscow, Russia. He is also Senior Research Professor at Eurasian Center for Big History & System Forecasting at Institute of Oriental Studies, Russian Academy of Sciences and Institute for African Studies, Russian Academy of Sciences, as well as at the Faculty of Global Studies of the Lomonosov Moscow State University. Beginning as an historian of Arabia, he made focused studies, such as seen in 'Two Social Ecological Crises and Genesis of Tribal Organization in the Yemeni North-East' (1996). Korotayev researches topics in quantitative cross-cultural anthropology and seeks to understand biological and social macroevolution, as in 'A Compact Macromodel of World System Evolution' (2005) and 'Mathematical Modeling of Biological and Social Phases of Big History' (2014). He has authored or co-authored over 650 scholarly publications,

including such monographs as *Ancient Yemen* (Oxford University Press, 1995), *World Religions and Social Evolution of the Old World Oikumene Civilizations: A Cross-Cultural Perspective* (The Edwin Mellen Press, 2004), *Introduction to Social Macrodynamics: Compact Macromodels of the World System Growth* (URSS, 2006; with Daria Khaltorina and Artemy Malkov), *Introduction to Social Macrodynamics: Secular Cycles and Millennial Trends* (URSS, 2006; with Daria Khaltorina and Artemy Malkov), *Great Divergence and Great Convergence. A Global Perspective* (Springer, 2015; with Leonid Grinin), *Economic Cycles, Crises, and the Global Periphery* (Springer, 2016; with Leonid Grinin), *Islamism, Arab Spring, and the Future of Democracy. World System and World Values Perspectives* (Springer, 2019; with Leonid Grinin and Arno Tausch). He is a founding member of the Eurasian Center for Megahistory & System Forecasting and founder of Evolution, an almanac dedicated to the study of Universal Evolution, and thus is closely linked with Big History. Recently, he has produced, with David LePoire, a collective monograph, *The 21st Century Singularity and Global Futures: A Big History Perspective* (Springer, 2020). He is a laureate of a Russian Science Support Foundation in 'The Best Economists of the Russian Academy of Sciences' Nomination (2006); in 2012 he was awarded the Gold Kondratieff Medal by the International N. D. Kondratieff Foundation. He serves as a board member of the International Big History Association.20, Myasnitskaya, Moscow 101000, Russian Federation.