Machine learning in astrophysical cosmology: Education beyond the dominion of Big Techs

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Abstract

This article discusses the adventum of artificial intelligence (AI) in people's daily lives, showing that the constructive side of AI is not within the reach of the average citizen, and not within the tool boxes of most academics in many countries. Demystifying AI, which is nothing more than multivariate statistics (MS) executed with high performance, and pointing to generative AI as an instrument for binarizing thought and deconstructing cognition, both practices of interest to some neoliberal corporations, the work presents a positive example of **R** language application of machine learning (ML) in astrophysical cosmology that demonstrates how it is possible to use AI with gains for cognition, and for critical and innovative thinking, preserving ethics and optimizing the use of the intellect. Finally, the study provides suggestions for formal secondary education in the sense of repositioning mandatory classical subjects in a right route, allowing not only the emancipation of the individual, but also access to the necessary means to develop additional cognitive skills to deal with an increasingly technological world, and to understand the ethics of using such skills.

Keywords: Artificial intelligence, Machine learning, Astrophysical cosmology, Galaxy clusters.

Resumen

Este artículo analiza la irrupción de la inteligencia artificial (IA) en la vida cotidiana, demostrando que su vertiente constructiva no está al alcance del ciudadano medio ni al alcance de la mayoría de los académicos en muchos países. Desmitificando la IA, que no es más que estadística multivariante (SM) ejecutada con alto rendimiento, y señalando la IA generativa como instrumento para binarizar el pensamiento y deconstruir la cognición, ambas prácticas de interés para algunas corporaciones neoliberales, el trabajo presenta un ejemplo positivo de la aplicación del lenguaje R al aprendizaje automático (AA) en la cosmología astrofísica, que demuestra cómo es posible utilizar la IA con beneficios para la cognición y el pensamiento crítico e innovador, preservando la ética y optimizando el uso del intelecto. Finalmente, el estudio ofrece sugerencias para la educación secundaria formal en el sentido de reposicionar las asignaturas clásicas obligatorias en una dirección adecuada, permitiendo no solo la emancipación del individuo, sino también el acceso a los medios necesarios para desarrollar habilidades cognitivas adicionales para afrontar un mundo cada vez más tecnológico y comprender la ética de su uso.

Palabras clave: Inteligencia artificial, Aprendizaje automático, Cosmología astrofísica, Cúmulos de galaxias.

I. INTRODUCTION

Cosmology (more specifically astrophysical cosmology), an offshoot of astronomy, is the physical science that seeks to describe the universe on large scale, its origin, its structures, and its evolution. Since the late 1990s, technological advances in observational astronomy have consolidated this science at a level far superior to that of the years in which a high degree of speculation about the immensity that surrounds us predominated. Importantly, and I have been repeating myself on this point, it is necessary to clear up here the frequent confusion between science and technology. The goal of science is not to produce technology, but rather to describe how the universe works under the laws that science itself identifies and formalizes. It is true that technology is initially based on fundamental science, but once the former is established, it advances on its own. Thus, the purpose of the General Theory of Relativity is to establish, on the basis of the space-time-gravity triad, the laws governing the universe at large scale, not to build a global positioning system (GPS), or spaceships to travel near light speed or "faster" than light. Likewise, the purpose of quantum mechanics is to describe the universe at microphysical scale, not to build a quantum computer. Clearly, technological advances can bring back benefits to science, especially in terms of corroborating its theories; for instance, the large orbital telescopes created since the 1990s, from the Hubble to the James Webb, have not only changed many of our beliefs about the universe, but have also provided data for successive confirmations of General Relativity.

Nevertheless, the uses of technology generally involve extra-scientific interests.

The theoretical foundations of contemporary cosmology lie in Einstein's General Theory of Relativity, from which different cosmological models, or cosmologies, were established according to considerations taken from theory, observations and from the substantial uncertainties involved. These cosmologies are characterized by specific solutions of Einstein's equations (EE), although not everything in cosmology directly links to these equations. The so-called Λ-CDM Model (Λ-Cold Dark Matter), also known as Standard Model, is the currently accepted cosmological representation of the universe. It was built on the Friedmann – Lemaître – Robertson – Walker (FLRW) homogeneous solutions of EE. However, inhomogeneous generalizations of FLRW cosmological model gained expression mainly by substantiating an alternative way of considering the accelerated expansion of the universe as a result of inhomogeneities in the distribution of matter, and not caused by dark energy (personally, I believe that both causes are concurrent to the accelerated expansion). The simplest inhomogeneous models of the universe are based on Lemaître-Tolman (LT) metric — sometimes referred to as Lemaître-Tolman-Bondi (LTB) metric —, which represents solutions to EE with spherical symmetry considering a resource of dust [1, 2, 3, 4]. The study of the LT inhomogeneous cosmology is at the core of my research in astronomy.

In addition to the current capacity to observe the deep cosmos on an unprecedented scale, computational processing power has brought significant gains for the analysis of large volumes of data and for the execution of complex simulations, although, in the latter case, the convenience of numerical solutions to differential equations has surpassed the interest in the search for analytical solutions, which weakens theoretical structures to a certain extent. This, in fact, is one of the symptoms of the emphasis on knowledge harming understanding, a characteristic of the principle of fast production, according to which everything must be ready in record time. It is following this reasoning that generative AI marketing gains space in the media, bringing with it the overthrow of the last bastion of rationality (since the other pillars such as ethics and esteem for truth have already been banned!): cognition.

The digital market likes to invent names to sell its trinkets that add nothing to science and cognition, and that materialize the ideological narrative of the digital world as "the better world". Bring on the tosh: "prompt engineering" (in just over two years of existence among the skills celebrated in the job market, it is already practically obsolete as such), "machine learning", and the very expression "artificial intelligence" itself, which, in Nicolelis' ironic words, is “neither intelligent nor artificial”. This is not surprising. After all, selling a pig in a poke has been a predatory practice of humankind since time immemorial. We are predators by nature; we sadly got here through the exploitation of many by few, no matter how much we do not want to admit it.

Unfortunately, we live in a dystopian world, ideologically shaped to make us abdicate our analogical mindset in favor of a binary behavior, without the nuances of reflective critical thinking. Therefore, the objective of this article, speaking a little about cosmology, is to discuss the ethical and purposeful use of AI, notably machine learning, showing the risks of generative AI for cognition and for the very analogical nature of human beings. The expectation is that the example of the application of AI in astrophysical cosmology can motivate researchers and students to know and understand MS, the basis of all AI, and to remain vigilant about their humanities, despite the digital technocratic ideology of the Big Techs. Perhaps, and I sincerely expect, the reader can find some motivation to learn more about cosmology.

II. A BIT ON ML IN COSMOLOGY

Apart from the dubious intentions of the AI market, there are certainly positive aspects to the use of AI, free from ideology. Mastering its theoretical foundations and algorithmic expression is what really contributes to scientific development, especially if we enhance the performance of classical algorithms with heuristic techniques. In other words, we first master MS, its applications, and the appropriate programming language (knowledge). Then, we identify in which circumstances we should resort to MS, and with which specific applications we should address the proposed problem (understanding). Finally, we interpret, discuss, and compare the results, providing a consistent conclusion (meta-understanding). In the nihilistic-hedonistic world of neoliberal ideology, however, this is a route that few are willing to follow. In the global mentality of prioritizing fun, consumption, and material comfort, shortcuts are the ideal choices; better ask ChatGPT, an instrument of consecration of the "future without a future", of plundering other people's efforts, of demolishing ethics and cognitive capacity. We continue to be predators, but there is a way out of this toxic behavioral pattern: mastering the sequence “knowledge → understanding → meta-understanding”, which originates in the human mind. To illustrate that way, let us now look at a relevant and educative application example of ML for cosmology.

II.I. ASSUMPTIONS AND METHOD

Two fundamental quantities for cosmology are the redshift (z), which corresponds to the distance of the astronomical object, and the magnitude (mag), which corresponds to its brightness. In the approach of this study, the equations to be integrated will reflect in a graphical representation the guide curve around which we get the distribution of galaxy clusters along z according to their magnitudes. As previously stated, the LT cosmology presupposes a universe with inhomogeneous distribution of matter. Locally, and on scales of millions of light-years, with superclusters of galaxies and extensive voids between them, inhomogeneity is indisputable. However, in terms of billions of light-years, the assumption of homogeneity has been considered reasonable and defended by most astronomers under what is called the "Cosmological Principle", including the isotropy of the universe, and, to a certain extent, introducing some important formal simplifications. Curiously, despite this defense, relevant facts about the universe and its structures are due to the inhomogeneities of the verified circumstances. The discussion shall continue for a while, but, in particular, I believe that homogeneity is really a simplification expedient, more than an acceptable outline of reality, and as such, on the scale at which it presents itself, it can introduce obstacles to a deeper comprehension of the cosmos. In any case, much of all this is about to collapse in face of the observations obtained with the James Webb. The recognition of the filamentary *petastructure* of the universe, with unimaginable gaps between the filaments, and the detection of early galaxies that conflict with the Standard Model have caused a certain paralysis of cosmology and desperate attempts to save something of the Cosmological Principle in its current version. Thus, the idea of a homogeneous universe even on a very large scale is becoming increasingly untenable.

If we assume that the universe is inhomogeneous, we cannot escape taking into account non-linear structures[1] such as galaxy clusters, and later, superclusters. Therefore, we are led to foresee a predictive non-linear dispersion extrapolated from the theoretical curve "red shift *versus* R-magnitude" (z X R-mag)[2] of the cosmology to form the virtual background to include any galaxy cluster candidates subsequently detected. In this way, an algorithm in **R** language creates the predictive scatter and compares it with observational data. Ultimately, it is a matter of deducing a predictive non-linear field that reflects the natural randomness of the system under discussion, providing the most likely representation according to the best fit of parameters **Ω** (density parameter) and c (adjusting constant of the model). The heuristic aspect of the method is precisely the application of a non-linear regression reverse engineering from the theoretical curve of cosmology itself (as if this curve were a non-linear regression curve of the observational data), creating the predictive field, a dispersion of the curve to be confronted to the data. Possible new cluster candidates added to the database should appear on that field, and the algorithm will doubt the accuracy of the data if a future candidate appears far outside the predictive field. This is a full example of what gives support to ML.

Variable or function	Meaning	Variable or function	Meaning
$R(r, t)$	Angular diameter distance	$R'(r, t)$	Spatial derivative of the angular diameter distance
$a(r, t)$	Scale factor	$\dot{R}(r,t)$	Time derivative of the angular diameter distance
z	Red shift	$a'(r, t)$	Spatial derivative of the scale factor
f	Arbitrary LT function (space-time curvature)	$\dot{a}(r,t)$	Time derivative of the scale factor
r	Co-moving coordinate (radius)	$A=\frac{1}{(1+cr)^2}$	Arbitrary LT function, with c as the adjusting constant already defined

TABLE 1: Meanings of the variables and functions involved in the LT cosmology.

Simulation from the author in **R** language

As can be seen, we have a complex intellectual construction as a result of a broad cognitive process involving several skills and accumulated prior knowledge. The machine only processes all of this "past" efficiently, returning to the intellect that fed it the results that would take incalculable time and effort to obtain by hand. Intelligence remains uniquely and exclusively human.

II.II. DATA COLLECTION AND THEORETICAL ANALYSIS

In my research, to model galaxy cluster's data I adjusted the theoretical LT curve to R-magnitude. The best fit of parameters **Ω** and c was choose as **Ω** = 0.3 and c = 2.2. Observational data was obtained from the KiDS survey and from the DES Collaboration [6]. To establish the theoretical curve of the indicated cosmology, we need to find the luminosity distance, *dL*, calculated from the radiation flux emitted by the source and measured by the observer. In general, observations are initially directed to the closest objects, which can be observed in a greater number of bands than more distant objects. From these observations, it is assumed that the resulting method of light curve conversion applies to all redshifts. We have the following system of differential equations to integrate (from which we obtain the luminosity distance)[3]:

$$\frac{dR(r,t)}{dz} = \frac{R'(r,t)}{(1+z)\dot{R}'(r,t)}\left(\sqrt{1+f} - \dot{R}(r,t)\right), \qquad (1)$$

$$\frac{da(r,t)}{dz} = \frac{1}{(1+z)\dot{R}'(r,t)}\left(\sqrt{1+f}\,a' - \dot{a}R'(r,t)\right). \qquad (2)$$

[1] See the recently discussed unusual asymmetry of the Andromeda Galaxy's satellite galaxy system [5].

[2] R-magnitude is a measurement of brightness using a filter (R-filter), depending on the photometry system adopted.

[3] Since dL is a function of z and $R(r, t)$ (see Table 1 to learn symbology).

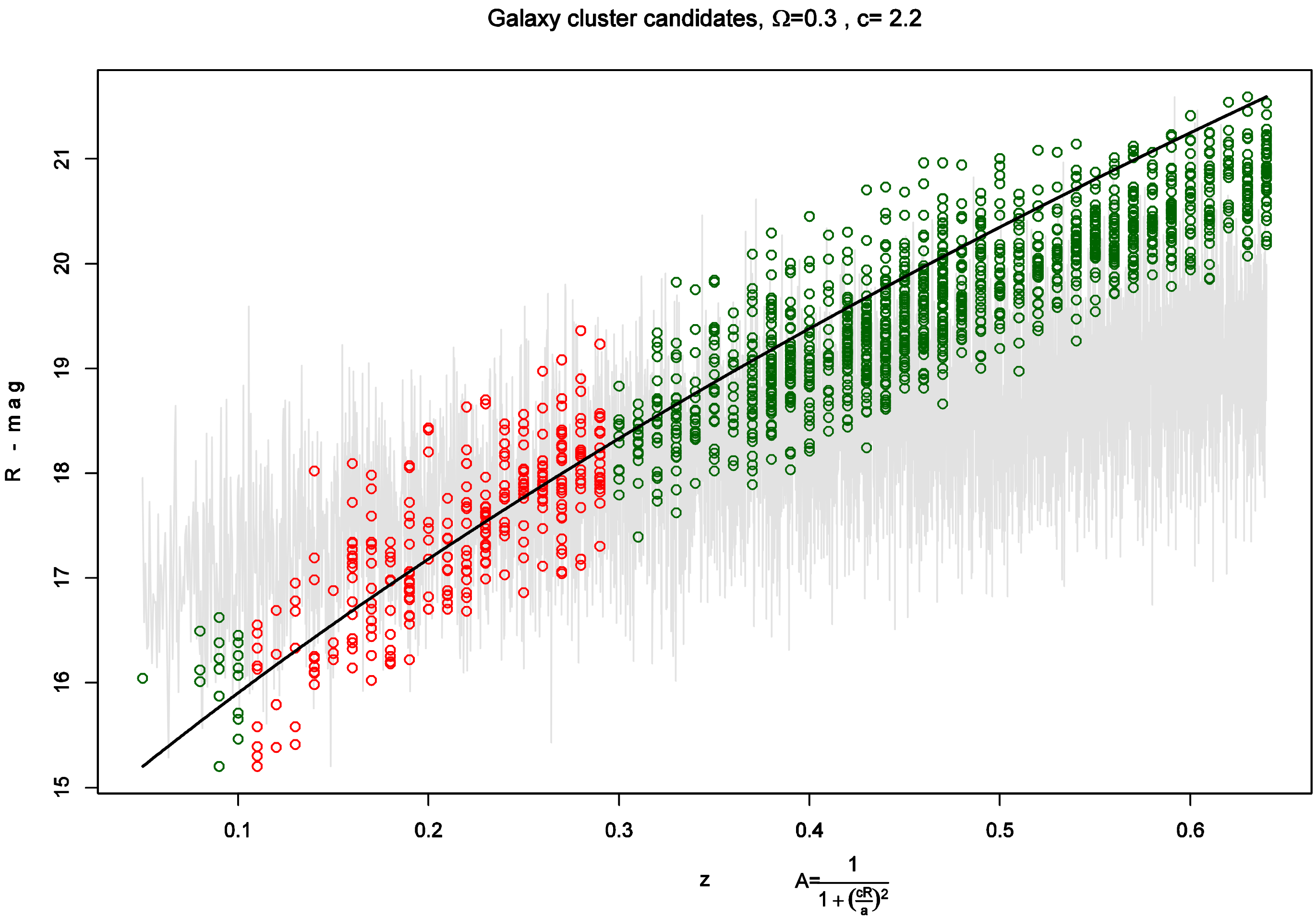

FIGURE 1: Theoretical curve of the LT inhomogeneous cosmology, and the non-linear expectation field in gray projected by the confrontation between theory and observational data (in red, the same *z* range previously little explored in investigations of type-Ia supernovae).

Simulation from the author in **R** language

Applying the technique mentioned above — the reverse engineering of non-linear regression on the theoretical LT curve provided by the integration of equations (1) and (2) —, I create a diffusion of the curve forming a non-linear inhomogeneous scattering field, a predictive field in gray from the points of the curve (Figure 1). Overlapping observational data — with the corresponding error bars on R-mag — and the non-linear field (Figure 2), we can see a consistent representation of the distribution trend of galaxy cluster candidates. The reader should understand that, for clusters with very close R-mag values, the separation of the representative circles is only visible with the error bars.

However, for the investigation to be complete, it is useful to compare the adopted model with the approach of Garfinkle [3]. He investigated two models, one for omega = 0.3 and c = 8.5, and another for Ω = 0.2 and c = 5.1. Since changes in the adjustment constant c only slightly alter the predictive field within the limits indicated in the study of the aforementioned author, and since that field is broad enough to overlap with other possible models, it is worth testing whether for Ω = 0.3, the choice c = 8.5 (Figure 3) constitutes simultaneously a plausible model, that is, covered in good approximation by the same predictive field defined with c = 2.2. To perform the test, a simple neural network is constructed, combining Ω and c, and assigning a TRUE/FALSE classification to the network's test probabilities in relation to the initial reference combinations of Ω and c (whose organization was inspired in the form of the XOR table). For probability values greater than 0.5, the combinations of Ω and c are classified as "T" (TRUE), otherwise "F" (FALSE). The resulting probabilities (Table 2) were applied to the calculation of the predictive fields, completing the ML algorithm.

Concisely, the algorithm predicts that, as *z* increases, new galaxy cluster candidates will tend to be located further below the theoretical curve. Thus, the general propensity is

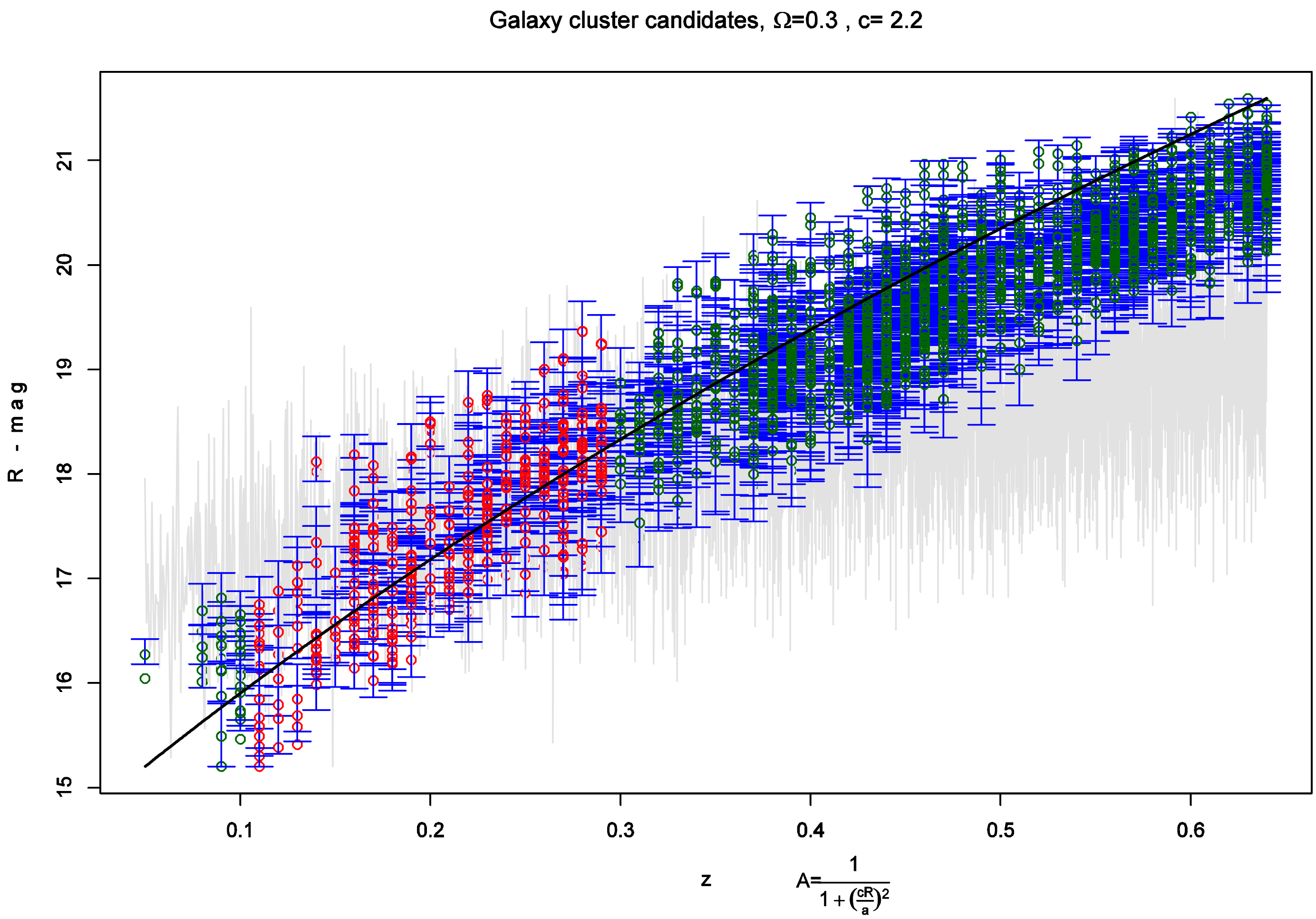

FIGURE 2: Same as FIGURE 1 with error bars (note that the extrapolation from de curve is coherent with the observational distribution of the cluster candidates, considering error bars in R-mag).

Simulation from the author in **R** language

expressed by the combination of theoretical curve and its dispersion, taking into account the observational scenario presented. The objections commonly made to the LT model due to the arbitrariness of the functions *f*, *a*, and A lose support as the predictive spread of the defined theoretical curve covers a whole range of virtual variations of the assumed parameters, which, consequently, ends up encompassing the FLRW cosmology itself in the nonlinear dispersion zone (in practice, the two cosmologies only differ significantly from $z \sim 0.8$). Lastly, the inhomogeneity of the universe constitutes a prospect that is increasingly difficult to contest given the accumulating evidence [7]. In the current scenario of general cosmology, it is worth testing this approach even though we have a lot to improve.

III. GENERAL DISCUSSION

ML can be useful to the extent that it is understood as a fertile ground for the flourishing of disruptive heuristic reasoning translated into operational techniques executed by efficient algorithms. In astrophysical cosmology, these techniques are indispensable, given the need to deal with the great uncertainties caused by the immeasurable distances that separate us from cosmic objects. The predictive character of the presented model offers the possibility of embracing such uncertainties not only as products of the deficiency of the means, but also as an inherent aspect of the natural non-linearity of the systems. It is not possible to access them with unlimited precision; it is the nature of things to deny us such precision.

There is, undoubtedly, an additional educational facet in the example explained. Astrophysical cosmology is the science that underpins the study of the origin of life, since it describes the evolutionary stages of the universe, identifying in which inhomogeneous physical circumstances, on large scales, life becomes possible (in fact, up until now, life seems to establish in a somewhat inhomogeneous way in the universe!). Like astronomy, its science-mother, it serves as a gateway to other sciences such as biology and chemistry. In addition, it develops in us

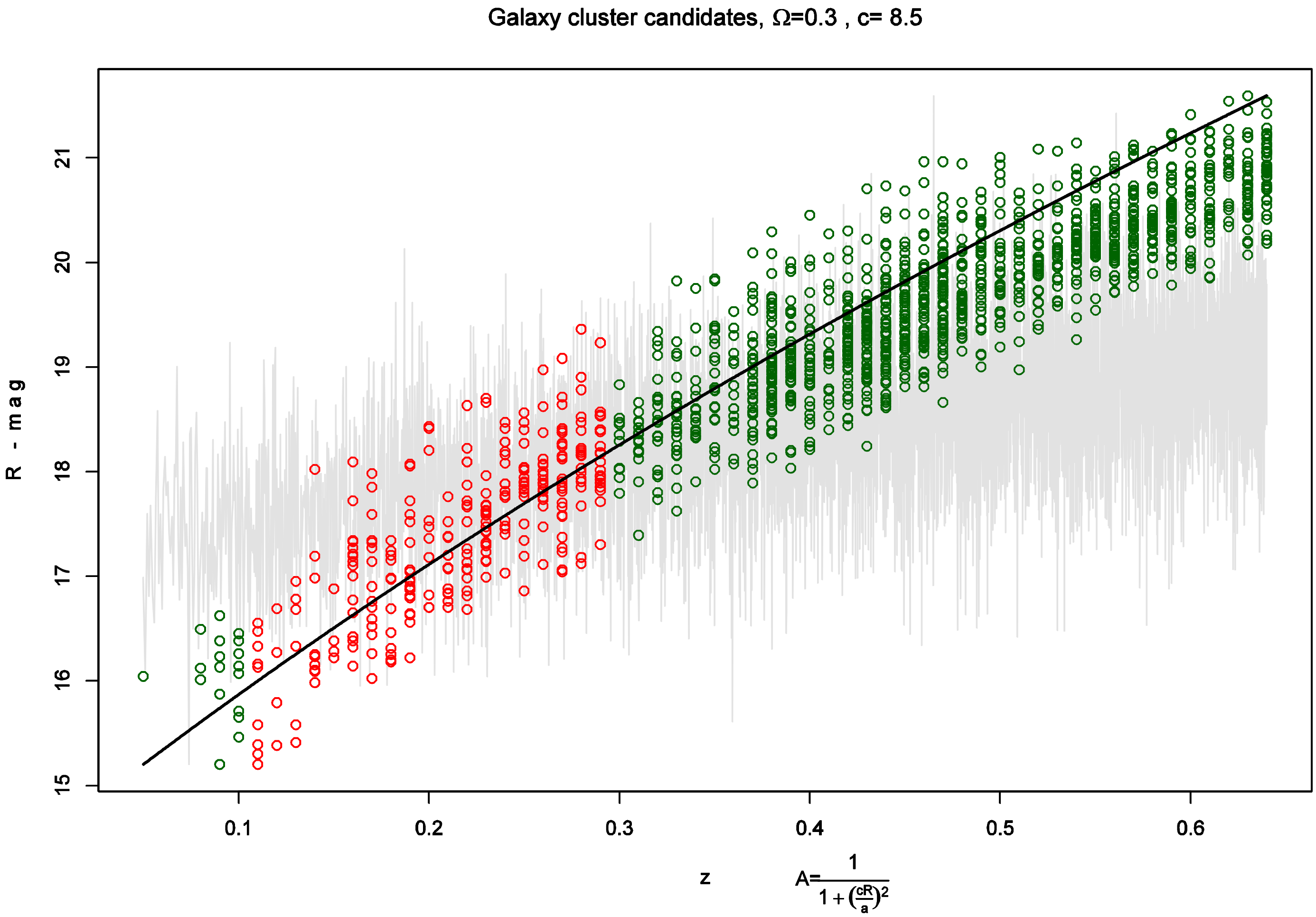

FIGURE 3: Same as FIGURE 1, but for c = 8.5 (note the slight difference in the predictive field).

Simulation from the author in **R** language

a sense of humility and appreciation for life and for our planet. If we had cosmologist politicians, I think our leaders would be less greedy and vulnerable to corruption. Astronomy should be learned from the first years of formal education as an indispensable subject for the formation of character.

II.II. SOME REMARKS ON AI AND EDUCATION

The ethical and propositive use of AI as I have presented will only be viable if it is taught from an early age in school life. Curricula should be reviewed at all levels, not to encourage the use of ChatBots, but to prepare the mind to benefit from the operational advantages of computational support. In this sense, statistics is a very valuable tool and can be taught in stages, from the first moments of secondary education, including early learning of the **R** programming language. In any case, it is necessary to emphasize that the machine only executes the algorithm summarizing the formal-logical dexterity of human rationality, but it lacks the intuition that permeated the creative phase of rationality, which is non-algorithmic [8, 9]. It is difficult to conceptualize intelligence and consciousness such is the non-algorithmic complexity of the brain and its mind. It is enough to hear the voice of a loved one, and later hearing it internally, through memory, with all the emotional connections simultaneously aroused in the moment of remembrance to understand the breadth of that complexity. I believe that the so-called AI will naturally become more useful when we no longer listen to the foolery disseminated by the media.

Over the years, under intense media fire, we have ended up lending to computers attributes that they do not actually possess, something suggested in terms like "human algorithm systems", in reference to algorithms for solving everyday “optimal stopping” problems [10], as for instance looking for an apartment (which in fact is not simply a logistical issue, but requires intuition, aesthetic sense, connection with the interior and exterior environments, perception of space, lighting and ventilation, etc.). It was the human heuristic improvement of the statistical basis of such algorithms and so many others that has been misleadingly marketed as AI.

Once again, it is necessary to reaffirm that in its different aspects, AI is nothing more than MS carried out by high-performance electronic processing devices. Thus, the constructive use of AI, i.e., the use that not only preserves cognition but also develops it, requires knowledge of MS, including how and when to apply it, in addition to mastery of an appropriate computational language with which to write the algorithms to be executed. It is knowledge (means), enabling understanding (goal), and building meta-understanding (meta-goal). The problem is that not many people want to focus their efforts on these things, mainly in the field of social sciences.

People in the social sciences are not generally enthusiastic about approaching the exact sciences in the sense of seeking to formalize some laws, a formalization that is not always mathematical [11]. However, I believe that, with respect to education, neuroscience — without being prescriptive as to teaching — can establish the axiomatic bases of a fruitful connection for the identification and enunciation of laws that unify the understanding of cognitive processes regardless of the always pointed out cultural differences, the main argument used by pedagogues and educators against rigorous scientific research in education. We need these foundations to identify what works or what does not work in the education of new generations out there, who discard from their dull lives the perspective of understanding that knowledge offers.

III. FINAL COMMENTS

Regarding cosmology, it is true that we can use AI in the constructive way I have shown here, but we need questions that make sense and that can be answered reasonably. Indeed, the future of the universe, as well as its beginning, are uncertain. Thinking about it, we do not even know if these questions make much sense. There is talk of gravitons with mass, compensating for the supposed tearing apart of the universe by dark energy in the distant future, but gravitons and gravitinos are as hypothetical as the multiverse. There is insistence on quantizing gravity, but I do not believe this is the way to follow; we would have to force the approximation between the two images of nature too much to the point of losing the deep understanding that these great representations brought at their respective scales of approach. As others have said, perhaps we really do need a new physics, and no AI will be able to build it. For now, a less pretentious cosmology already opens up more than enough realistic discussions for the general understanding of the observable universe. In a nutshell, we need to overcome the current phase of lack of objective purposes, something that affects everything and everyone, including science; less speculation and more assertiveness.

The mediocrity of thought, the culture of neomodernist relativism and the trivialization of education are sad marks of our time. Especially in Brazil, the situation is chaotic, aggravated by a high rate of functional illiteracy. This illiteracy, which abounds among government agents themselves, reaches the classes and lectures frequently given via ChatBots, apparently without any major concerns. I always remember that in the 90s a Japanese colleague told me that science would soon be replaced by technology. At the time, I thought the statement was a bit exaggerated, but, seeing the current scenario, I fear he was right. In fact, the lack of interest in the search for understanding, giving preference to technical facilities, is growing.

Prediction: Ω = 0.3 , c = 2.2 => 0.988989280391839 TRUE Call: lm(formula = table[, 7] ~ table[, 3]) Coefficients: (Intercept) table[, 3] 15.648 8.425	Prediction: Ω = 0.3 , c = 8.5 => 0.504175329205569 TRUE Call: lm(formula = table[, 7] ~ table[, 3]) Coefficients: (Intercept) table[, 3] 15.648 8.425

TABLE 2: Predictions for c = 2.2 (best fit) and c = 8.5, both classified as TRUE with the latter on the probabilistic limit. The calls on "table[, 7]" and "table[, 3]" refer to R-mag and *z* respectively.

Simulation from the author in **R** language

We urgently need to put such foundations into new practices, including adopting a more disruptive science in face of so many interesting open problems that seem to have no solution with the traditional models we have [12]. Despite the crystal-clear logic of these considerations, many refuse to accept them, preferring the simplistic argument that the world has changed; therefore, education must change, either by force of the ideologies that permeate the institutions of the neoliberal model or by force of the technologies imposed on us, or even by a toxic combination of both. With the thoughtless entry of AI into educational environments, this toxicity tends to be irreversible.

For at least 30 years, and most severely in the period between 2010 and 2024, education has suffered serious damage with the introduction of the so-called "new pedagogies", which were implemented without any metrics to validate their effectiveness. If we observe the undeniable decline in the quality of global intellectual production over the last few decades, the negative results for the emancipation of people and for the integral formation of citizens are remarkable. Professional qualifications are unsettled in several areas, and critical thinking is disappearing. Of the brilliant minds forged in traditional education (Woodger, Montagu, Turing, Wiener, Popper, Bunge, Bohr, Einstein, Heisenberg, Russell, Poincaré, Whitehead, Wittgenstein, Somerfeld, De Broglie, Asimov, Schrödinger, Zel'dovich, Hubble, Lemaître, Sunyaev, Clark, Bachelard, Llosa, Aron, Huxley, Reichenbach, Freud, Jung, Tomonaga, Hoyle, Schwarzschild, Gödel, Milton Santos, Darcy Ribeiro, among so many others), few are remembered as examples to inspire us, and it is very clear that we shall not see new minds as brilliant as until the first half of the 20th century if we continue to adhere to the binary model of thinking subliminally propagated by the market of AI.

Many academies contribute to this dismal picture, keeping their little groups polarized in hive minds, while in the world outside the walls people prefer to consume technology and platitude rather than acquire formal education, and so on in this cultural downfall we are experiencing. "Don't know much about history, don't know much biology, don't know much about a science book […]", said Sam Cooke' song from the 60s, opening the doors to the society of the spectacle we are leaving.

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