The new history and fate of the Universe chart from the Contemporary Physics Education Project

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Abstract

The Contemporary Physics Education Project (CPEP) is a nonprofit organization founded almost 25 years ago to produce charts and other materials exhibiting areas of ongoing physics research in colorful fashion. In 2015, the Contemporary Physics Education Project (CPEP) significantly revised the original cosmology chart. Details of the new chart are presented as well as differences between the original and new charts. Anyone with an interest in astrophysics or in using astrophysics to attract student interest can use the chart and ancillary materials for self-learning or teaching. Ways to use the Universe Adventure and the chart with students are discussed, as well as ideas for more ways of using the chart effectively with students.

Keywords: Contemporary Physics Education Project, cosmology chart, Universe, astrophysics.

Resumen

El Contemporary Physics Education Project (CPEP) es una organización sin fines de lucro fundada hace casi 25 años para producir gráficos y otros materiales de las áreas de investigación en curso en la manera colorida de la física expositoras. En 2015, el Proyecto de Educación de Física Contemporánea (CPEP) revisó significativamente el gráfico original de la cosmología. Los detalles de la nueva carta se presentan, así como las diferencias entre los gráficos originales y nuevos. Cualquier persona con un interés en la astrofísica o el uso de esta para atraer el interés del estudiante puede usar el gráfico y materiales auxiliares para el auto-aprendizaje o enseñanza. Maneras de utilizar el Universo Aventura y el gráfico con los estudiantes son discutidos, así como ideas para más formas de utilizar la tabla de manera efectiva con los estudiantes.

Palabras clave: Contemporary Physics Education Project, carta cosmológica, Universo, astrofísica.

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I. INTRODUCTION

The first version of the History and Fate of the Universe chart developed by the Contemporary Physics Education Project (CPEP) was completed in late 2002. We were proud of the representation other CPEP members developed through discussions with CPEP member George Smoot, who later won the Nobel Prize for his work on the fluctuations in the temperature of the early universe revealed in data from the Cosmic [Microwave] Background Explorer (or COBE, as it is known) [1].

Ref. 1 begins with this introduction:

> "The observables of modern cosmology include the Hubble expansion of the universe; the ages of stars and clusters; the distribution and streaming motions of galaxies; the content of the universe (its mass density and composition and the abundances of the light elements); the existence, spectrum, and anisotropy of the cosmic microwave background (CMB) radiation; and other potential backgrounds in the infrared, ultraviolet, x-ray, t-ray, etc. The purpose of the COBE mission is to make definitive measurements of two of these observable cosmological fossils: the CMB radiation and the cosmic infrared background (CIB) radiation" [1].

Their results were summarized as "the spectrum of the cosmic microwave background is that of a black body of temperature T = 2.73 ± 0.06 K, with no deviation from a black-body spectrum greater than 0.25% of the peak brightness" and data "show statistically significant cosmic microwave background anisotropy, consistent with a scale-invariant primordial density fluctuation spectrum." These background fluctuations from uniformity in temperature are correlated with fluctuations in matter density in the early universe.

The matter density fluctuations, in turn, give rise to the observed distribution of matter, which is visibly clustered in galaxies scattered (seemingly randomly) in space. The galaxies, however, are clustered. Astronomers speak of galactic clusters that are gathered in gigantic "walls" and "voids."

The Hubble expansion from the big bang about 13.8 x 10^9 years ago. In 1998, two experiments using type Ia supernovae as "standard candles," that is, fixed luminosity events that can be used to determine the distance to the supernova using the inverse-square relation for intensity, found that the universe began expanding more rapidly –or accelerating– about 5 x 10^9 years ago, [2, 3]. An excellent review explaining the background of the result is found in reference [4]. Data from fifty-eight supernovae were analyzed to obtain the results.

To the members of CPEP, these advances called out for a fourth chart of contemporary physics to supplement the particles and interactions, plasma physics, and nuclear physics charts that had been produced.

II. THE ORIGINAL HISTORY AND FATE OF THE UNIVERSE CHART

Clearly, the chart would need to address the sequel to the big bang. Several astronomical puzzles exist. Why was the temperature distribution so uniform? The fluctuations were tiny.

It was as if all parts of the universe were coexisting in equilibrium, but how could such uniformity apply to the aftermath of an explosion? Additionally, the matter density could be such that the pieces of matter flying off would be so strongly attracted through gravitation, that the universe would recontract and disappear into a "big crunch."

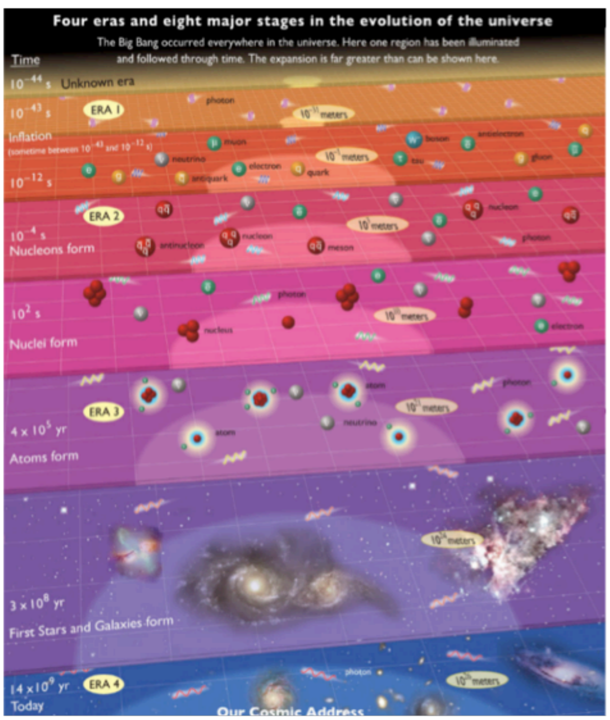

FIGURE 1. The representation of universe expansion in the first published.

The density of the matter in the universe from the continuing expansion observed must be remarkably close to the so-called critical density, a balance point between too weak and too strong. Such fine-tuning seems a priori unlikely. It was difficult to imagine how this could have happened.

Alan Guth suggested that there had been a very short time during which the universe expanded exponentially [5]. This sequence of events was difficult to visualize

We decided on a representation that was akin to water flowing down a wall to show the eras.

The eras –big bang, first expansion, inflation, formation of nucleons, formation of nuclei, formation of atoms, formation of stars and galaxies, and continued expansion to the present– flow from the big bang at the top to today.

The smallest sized version of the chart has additional material printed on the back that, could not be accommodated on the front despite the relatively large amount of text on the chart's original version.

The topics addressed are: gravity and expansion; the big bang had no center; redshifts and expansion; measuring cosmic distances; observed brightness and actual luminosity; antimatter; formation of nuclei; current composition of the universe; dark matter and particle physics; dark energy; and attributes of the universe. These provide support for the main chart (this continues on the current chart).

Additionally, just as there is a Particle Adventure website supporting the particles and interactions chart, there is website for the support of the cosmology chart: The Universe Adventure [6].

The cosmology chart also addressed the acceleration of the universe, as seen in Figure 2. The figure was created using the data available at that time.

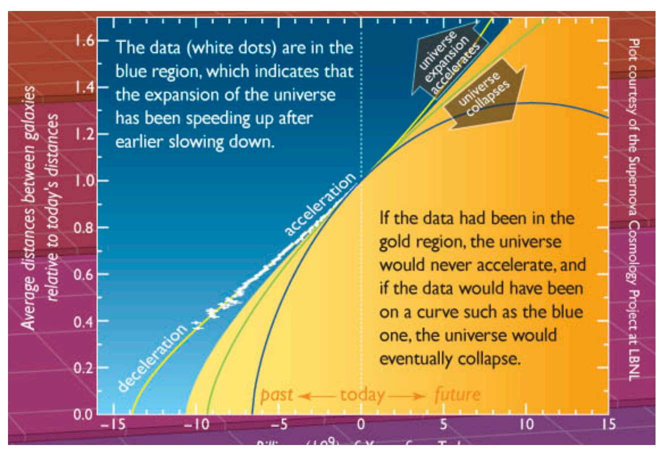

FIGURE 2. The universe accelerating (data as of 2002).

Despite our having tested the chart and the main image extensively, over time it became apparent that the diagram of Figure 1 was not as helpful to teachers as we had anticipated, nor was it accessible to students who wished to learn more. CPEP therefore undertook to revise the chart starting in 2014.

II. THE CURRENT VERSION OF THE HISTORY AND FATE OF THE UNIVERSE CHART

The failure of the central image to engage viewers and teachers as we had expected led us to consider a more linear representation of the eras referred to above, from the big bang to the present time. In Figure 3, the outer "edge" or envelope gives an indication of the relative size of the universe (of course, the size change due to inflation is grossly underrepresented).

The flat slices or sections, attempt to show characteristic structures at that age and stage. In the smallest segment is, presumably, pure energy a (not shown). In the first section are neutrinos, electrons, gauge bosons, and quarks (this is known as quark-gluon plasma).

By the next section, the quarks have clumped together to produce nucleons in addition to electrons, neutrinos and gauge bosons. In the following section, nuclei have formed.

This is followed in successive sections by atoms, then by stars and galaxies, then into the present, where humans are first portrayed. Labels for each section along the diagram show the time since the big bang and the mean photon energy of the microwave background.

For example, the first section shows the universe at 10^{-36} s and mean photon energy of 10^{14} GeV, or highly energetic gamma rays, while the label describing the present time lists 13.8 x 10^{9} years and 2.3 x 10^{-15} GeV, or microwave energies.

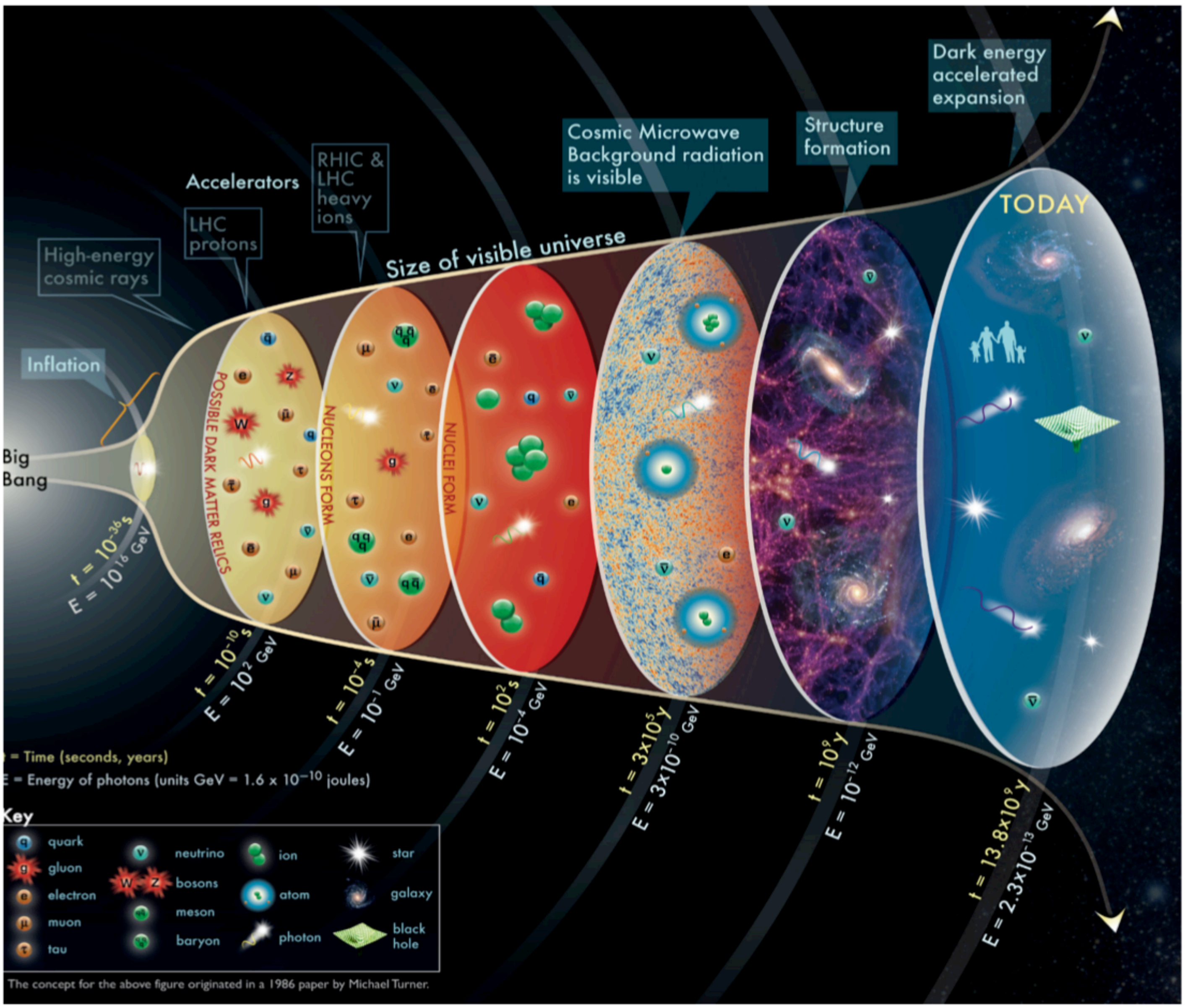

FIGURE 3. Alternative picturing of the sequence of events from the big bang to the present (and on to the future).

In addition, more data from observations of supernovae of type 1a are available currently than were available in 2002.

There is a considerably greater number of data points represented, as can be seen on the updated version of Figure 2, which is presented in Figure 4.

In both versions of the chart, we attempt to give observers a sense of the scale of astronomy with a section titled "Our cosmic address". This is shown in Figure 5. Beginning from Earth (to the left), the pictures are of successively larger structures: the solar system, the galaxy, the local group of galaxies, the local supercluster of groups, and, finally, the visible universe.

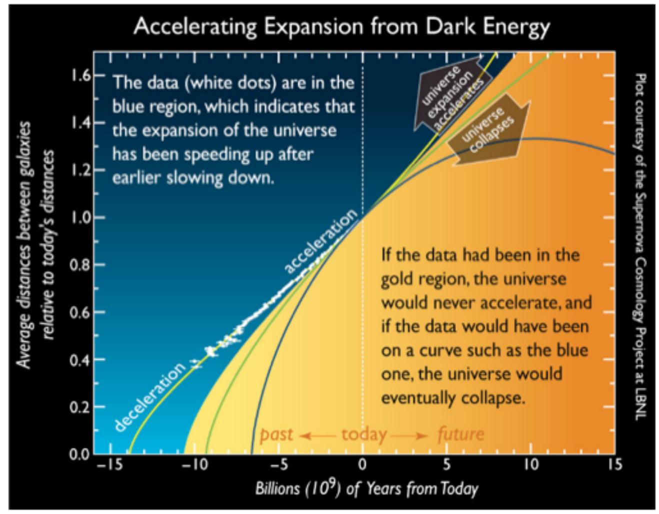

FIGURE 4. The universe accelerating (data as of 2015).

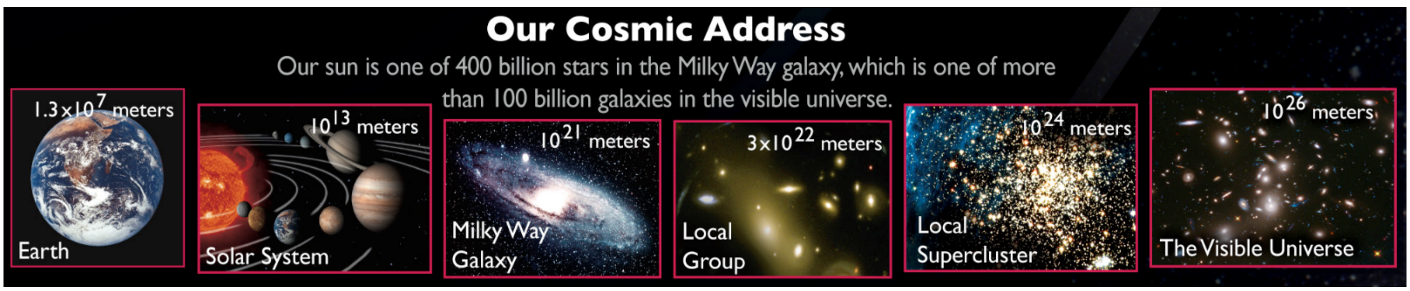

FIGURE 5. Our cosmic address.

VI. CONCLUSION

In conclusions, CPEP has created a newer version of the classic chart that both updates and expands the way we perceive the evolution of the universe. This version is visually arresting (as was the original), and we trust it will continue to attract students' wandering eyes and expose them to some new ideas in cosmology.

The wonder that all that we can see constitutes just about 5% of the matter density of the universe is mind-boggling and can help teachers think more deeply about the visible universe and the invisible universe awaiting greater human understanding. Overall, we hope that the newest version of the History and Fate off the Universe chart will prove attractive to teachers and welcome perusal by students.

ACKNOWLEDGEMENTS

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CPEP members are all volunteers. As chair emeritus, I am extremely grateful to all CPEP members who gave so freely of their time to create the original chart and its latest incarnation. While many CPEP members contributed to this work, Michael Barnett and George Smoot in particular contributed outsized efforts to its completion.

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