Cosmology and mathematical singularities: A historical perspective

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Topics:

- ➢ Who was the 1st to discover the Universe expansion?

- ➢ And that it had an origin? - BVG theorem

- ➢ The meaning of singularities

- ➢ Are there any physical singularities?

- ➢ Concluding remarks

Some facts:

➢ Four-year-olds mantra "the Universe expands!"

✓ And accelerates!!

➢ We now "know the truth": Lemaître, *not* Hubble!

➢ Unbeatable mantra: Big Bang = huge explosion (?!)

✓ (Of what? What exploded?)

➢ …

On Mar 14th, remembering Stephen Hawking 6th:

➢ Singularities, origin of space & time

✓ Someone disagreed!

➢ Lemaître discovered this, decades before!

Who was the 1st to **discover** the Universe expansion?
And that the Universe had a beginning?

DISCOVER

What does this word actually mean??

Two Decks of Cards (or Two Levels):

1. Speculations, intuition, guess, half-proofs, ...

2. Rigor, thms, precise experiments & observations

HUBBLE *vs* LEMAÎTRE

Until recently: Hubble was the great discoverer

Now: Lemaître did the whole job, and *before* Hubble!

→ Even Friedmann has lost relevance

Let's shed light on this conundrum

EDWIN HUBBLE

Common lore:

Hubble obtained distances, redshifts, Hubble's law
Concluded: *our Universe expands!*

Actually:

Only distances, law 2y after Lemaître, never believed
the Universe was expanding (for good reasons!)

He was a true scientist, played deck of cards N.2

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GEORGES LEMAÎTRE

Stounch supporters assure:

He did everything: obtained Friedmann's solution, Hubble's law, proved Universe expands & has an origin

But actually:

He borrowed all data, obtained a wrong solution, just guessed (or *half-proved*) that the Universe expands, Einstein and Eddington told him about Friedmann's sol

Strong math background, but intuition: played cards1

Lemaître Conference 2024
Vatican Observatory
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THE TWO PLAYING FIELDS

N.1:

Lemaître, Friedmann (good maths, discussed possib., level 1), ...
Rigveda: *Hiranyagarbha* (*Golden Egg*)

N.2:

Hubble, Einstein, Eddington, Hoyle, ...
Hawking, Penrose, ...
Guth, Borde, Vilenkin, ...

One of the principal problems studied by the **Landau group in Moscow**:

Do relativistic cosmological models *necessarily contain* a time singularity? Or time singularity is *an artifact* of assumptions used to simplify these models (Belinsky Lifshitz Khalatnikov 1963)

Singularity Theorems: Penrose, 1965; Geroch, 1968; Hawking-Ellis, 1973; Wald, 1984.

Theorem 1 (Big Bang). Let (M,g) a global hyperbolic spacetime satisfying Einstein's Eqs. with the strong energy condit. If there exists a spatial Cauchy C² hypersurface, Σ, for which the trace of the intrinsic curvature satisfies K<C<0, C const. (a trapped surface), then no temporal curve starting from Σ and going towards the past can have a length that is larger than 3/|C|(all temporal geodesics to the past are incomplete).

➡ Under conditions observed in our Universe and admitting GR, our Universe had a beginning

Theorem 2 (Black Holes). Under same conditions, for future time, there exists at least a light-like geodesic, which cannot be extended to the future. A photon will definitely fall into a future t-singularity. ➡ Need quantum gravity to know the physical nature of the singularity

Counterexamples:

- ✓ The Senovilla metric is a solution to Einstein's field equations, J.M.M. Senovilla, Phys. Rev. Lett. 64, 2219 (1990). It describes a Universe without Big-Bang and spatially inhomogeneous with a perfect fluid source.

- ✓ Bob Holdom, *"Nonsingular solutions to the Einstein equations on piecewise-Lorentzian manifolds"*, Phys. Rev. D107 (2023).

On the BGV (Borde,Guth,Vilenkin) Theorem

➢ Inflationary cosmological models seem to invalidate the conditions of the singularity theorems [1981-83: Guth, Linde, Albrecht, Steinhardt, Vilenkin]

➢ In the 80's, it was attempted (without success) to construct models that, starting from an exact dS solutions, would be past eternal

In 1994 Borde and Vilenkin proved an extended theorem: inflationary spacetimes are past geodesically incomplete

➡ an initial singularity

Borde, Guth & Vilenkin: "*Inflationary Spacetimes Are Incomplete in Past Directions*", PRL 90 (2003) 151301

➢ Quantum corrections to inflationary models seem to violate WEC when quantum fluctuations result in an increase of the Hubble parameter: $dH/dt > 0$ (essential for chaotic inflation to be eternal!)

➢ Thus, WEC must be gener. violated in those models! One must start from a "quasi dS" with a minimal condition of "averaged expansion": $H_{av} > 0$

➢ Theorem can be extended to extra dimension & cyclic models

➢ In all cases: geodesic incompleteness! ⟹ An origin!

Review

Mathematical Singularities in the Farthest Confines of the Universe—And a Brief Report on Its Evolutionary History

Emilio Elizalde

It will be here argued that, as a matter of fact, there are no infinities in physics, in the real world: all that appears, in any given formulation of nature by means of mathematical equations, actually arises from extrapolations, which are made beyond the bounds of validity of the equations themselves. Such a crucial point is rather well known, but too often forgotten, and is discussed in this paper with several examples; namely, the famous Big Bang singularity and others, which appeared before in classical mechanics and electrodynamics, and notably in the quantization of field theories.

A singularity means: new physics is needed!

➢ Einstein realized already that GR is not final *("... someone will improve it soon")*

➢ We know definitely that GR fails altogether at small distances (high energies)
[try, please, to describe an atom with it]

➢ No sense to take singularity theorems as final

⟹ Need QG, LQC, or the like

➢ Singularity theorems are extremely important and powerful

➢ Their authors deserve all kinds of recognitions and awards

➢ Singularities show us the path that remains to be taken and the direction in which we must concentrate our future efforts

➢ They quantify the difficulty of the peaks that are yet to be reached

THE **TRUE STORY** OF **MODERN COSMOLOGY**

Origins, Main Actors and Breakthroughs

This book tells the story of how, over the past century, dedicated observers and pioneering scientists achieved our current understanding of the universe. It was in antiquity that humankind first attempted to explain the universe often with the help of myths and legends. This book, however, focuses on the time when cosmology finally became a true science. As the reader will learn, this was a slow process, extending over a large part of the 20th century and involving many astronomers, cosmologists and theoretical physicists. The book explains how empirical astronomical data (e.g., Leavitt, Slipher and Hubble) were reconciled with Einstein's general relativity; a challenge which finally led Friedmann, De Sitter and Lemaître, and eventually Einstein himself, to a consistent understanding of the observational results.

The reader will realize the extraordinary implications of these achievements and how deeply they changed our vision of the cosmos: From being small, static, immutable and eternal, it became vast and dynamical — originating from (almost) nothing, and yet now, nearly 14 billion years later, undergoing accelerated expansion. But, as always happens, as well as precious knowledge, new mysteries have also been created where previously absolute certainty had reigned.

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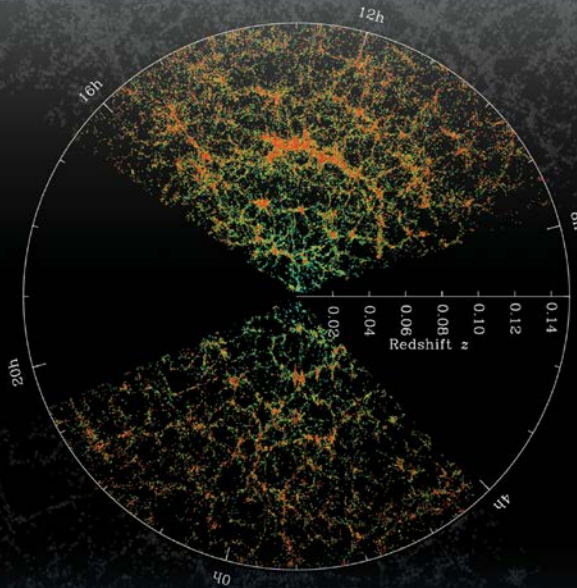
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Review
Einstein, Barcelona, Symmetry & Cosmology: The Birth of an Equation for the Universe

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Some Issues on the Foundations of Modern Cosmology, Gravitation and Quantum Physics

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Zeta Functions and the Cosmos—A Basic Brief Review

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The first cosmological revolution of the XXth Century

The first revolution can be framed in the period 1912-1932

➢ From the discoveries of Leavitt and Slipher to those of Hubble, and includes the theoretical advances made by Einstein, Friedmann, de Sitter, and Lemaître

➢ It came to its peak in 1929, with the publication of Hubble's results, confirmed in 1931

➢ Eventually, the scientific theory of the expansion of the universe having an origin was adopted by specialists and formulated in the celebrated Einstein-de Sitter model of 1932

➢ Anyway, its completeness still had to wait for:

  o the elaborate formulation of the Big Bang model

  o for its definitive test through the detection of the cosmic background radiation (CMB)

  o and for a major reshaping (inflation), which would only arrive fifty years later and was actually the prelude of the second revolution

The second cosmological revolution of the XXth Century

The second revolution occurred in the period 1985-2005

➤ Indeed, it may be affirmed that it started in the mid 1980s already, with the first discussions of a fitting cold dark matter model endowed with a possibly non-vanishing Λ-term

➤ It came to its peak in 1998-99 when the supernovae results appeared

➤ But it was not fully confirmed until some six years later, by other very important surveys

➤ The ΛCDM theory that was being built around various cosmological results had its most impacting confirmation through the astronomical discovery of the accelerated expansion rate using Type Ia supernovae as standard candles

➤ But these results just confirmed what other astronomical observations and the theoretical fits had been stubbornly indicating for some time already: that the expansion was accelerating!

➤ Modified gravity models and the use of Λ provide solid theoretical frameworks to try to understand this astonishing fact, based on the fundamental laws of physics

➤ But so far no one has convincingly succeeded

Institute of
Space Sciences

The similarities between the two revolutions are remarkable

➢ Their gestation period was exactly the same: 20 years in both cases

➢ In addition, there were always some prominent leaders who pretended to be the actual discoverers and tried to claim all the merit of the breakthroughs exclusively for themselves

     o Hubble and his Mount Wilson observatory, in the first case

     o Riess, Perlmutter et al. and their SNIa observations, in the second

➢ What we have here discovered is that those claims were not sustained

➢ The story was much richer and complex (Peebles) involving many other crucial contributions along the way leading to the findings and to the final confirmation of the discoveries

➢ It is also true, moreover, that the cosmological revolutions I am talking about cannot be identified by looking only at what happened during those 20-year time intervals

➢ I have to admit that this may be just a sketchy approach, a possibly too crude simplification

Please, compare with other famous revolutions

➢ Then, what I said is quite understandable

➢ If we take the French Revolution, it cannot be reduced to the events of 14 July 1789

   o Revolutions are always long and extensive in time, and seldom occur in a linear or coherent manner

   o Nevertheless, in the end, they produce great transformations in the thinking, behavior, and organization of people and societies

➢ As for the case of the famous Scientific Revolution, it took place during what historians often call the "long XVIIth century"

➢ Extends from the XVIth c., with the first investigations in anatomy and astronomy using modern techniques, until Darwin himself, well into the XIXth c. (some cut before)

➢ A very long period, in which much of what we now recognize as Science was slowly condensing; for the first time materialistic explanations were sought in all areas of research

➢ At the heart of the 1st revolution in Modern Cosmology (1912-32): Henrietta Leavitt, Vesto Slipher up to Edwin Hubble, and includes theorists A Einstein, A Friedmann, W de Sitter & G Lemaître

➢ Had to wait for elaborate formulation of the Big Bang model, final verification of the cosmic background radiation (CMB), and still for an important and crucial remodeling (inflation), prelude of 2nd revol.

➢ 2nd revolution (1985-2005): Univers expansion <u>accelerates</u> !?!?

➢ 1923: *A pivotal episode in the history of physics, of cosmology and, even further, of all Human History*