Cosmology: Science between Facts and Faith

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Abstract

The standard cosmological model rests on a never-ending array of hypotheses and assumptions (dark matter, dark energy and others) which either cannot be proved or, although theoretically possible, cannot yet be proved experimentally. This lack of secure knowledge raises legitimate doubts over the validity of the Big Bang model, which therefore cannot be seen as the ultimate answer to the question of the emergence and evolution of the universe. If the search for dark matter and dark energy turns out to be unsuccessful, the whole construction will break down and we will unavoidably face the question of which of the many different models based on Einstein's field equation represents the real world.

Keywords: redshift, Enstein – Einstein – deSitter, dark matter, dark energy, inflation

1. Introduction

The era of science-based cosmology began in 1917, when Einstein applied his Theory of General Relativity to the universe as a whole [1]. Assuming that the universe is homogeneous and isotropic on the large scale (the Cosmological Principle) and that the physical laws as known from terrestrial mechanics are the same across the whole universe (the Principle of Universality), Einstein found a surprisingly simple solution that implies an expanding universe:

$$v^2 = \frac{8\pi G}{3}\rho_{M,obs.} \tag{1}$$

According to Equation (1), the universe should either be contracting or expanding, with a velocity proportional to its mass density. The idea of the expanding universe was born but not accepted. Einstein firmly believed that the universe was static, and he therefore modified his result; his ad hoc introduction of a hypothetical cosmological constant Λ into his field equation led to the construction of a homogeneous, static, temporally infinite but spatially finite, flat universe, unchanging in size.

In 1929, Hubble published his famous "… relation between distance and radial velocity among extra-galactic nebulae" [2]; Einstein, convinced by this impressive data set, changed his mind and finally accepted the velocity interpretation of Hubble's Law. Together with de Sitter [3], he set up a model for an expanding universe that became the basis for Big Bang cosmology.

It should be mentioned that the interpretation of Hubble's Law as recession velocity—the basic pillar of Big Bang cosmology—was more a question of belief (supported by the analogy of the physically well-understood Doppler effect) than the compelling consequence of underlying astronomical observations. Today, the velocity interpretation enjoys the status of the principal dogma of Big Bang cosmology, and doubts about this are considered to be obviously unfounded.

2. Basic Assumptions of the Big Bang Cosmological Model

According to the basic assumptions of the Big Bang model, the universe began 10–20 billion years ago as a primeval fireball of infinite density and temperature, from an instantaneously expanding point (singularity), and has been expanding and cooling ever since. The tearing force of the expansion is assumed to be the outward impulse of the primordial Big Bang, and the velocity of expansion is given by Hubble's constant, $H_0 = 72.8$ km s^{-1} Mpc^{-1}. It is assumed that over time, gravity will slow down the outward velocity.

3. Observations Contra Theory

However, scrutiny of the astronomical data has revealed significant discrepancies between theory and observation. A few examples of these are the fine-tuning problem, the horizon problem, the age problem and the missing mass problem. The missing mass problem arises from the paradigm of the Big Bang theory, i.e. kinetic energy = ½ gravitational energy, according to which the critical mass for a flat universe $3H^2/8\pi G$, ($H=72.6$ km s^{-1} Mpc^{-1}) corresponds to a mass density of $\approx 10^{-29}$ g cm^{-3}. In contrast, the density of matter observed so far amounts only to a few percent of the critical value.

There are fatal contradictions between observation and prediction in the Big Bang theory. In any other field of physics, such a theory would have been abandoned for reasons of irremediable disagreement with observation.

4. The Lambda Cold Dark Matter (ΛCDM) Cosmological Model

Instead, new hypotheses were devised in order to make the Big Bang model consistent with observation. The majority of astronomers are convinced that large quantities of some unidentified dark matter (DM) pervade the universe. Astronomers also suspect the existence of dark energy (DE), which would produce the accelerated cosmic expansion [4]. If DM and DE are assumed, the Big Bang model can match each of the critical observations arising from the missing baryonic mass. The newly introduced but still elusive dark components have an impressive explanatory potential, and with these, the ΛCDM model can explain

- the origin and expansion of the universe,
- the abundance of light elements, and
- the existence of the 2.7K cosmic microwave background (CMB), among others.

At the same time, however, DM and DE produce other grave problems of no less importance than the old ones, which in turn require new hypotheses to explain them.

5. The Dark Energy Problem

The cosmological constant Λ is usually interpreted as the energy contained in empty space, i.e. the zero point energy of the quantum vacuum. However, the estimated energy of the vacuum exceeds the value required by the ΛCDM model by 120 orders of magnitude. This is the most momentous discrepancy between theory and observation known in astrophysics. For resolution of the problem, one may assume that the positive vacuum energy is cancelled out so precisely by some other negative quantity that only the required value remains. This would demand an incredible fine tuning of the positive and negative energies, which is extremely unlikely.

In recent approaches, several forms of varying cosmological constants have been introduced into the Einstein equations, and a number of authors have constructed models in which specific decay laws are postulated for Λ. Examples of phenomenological Λ-decay laws are summarized in [5]. The most prominent example is quintessence, a hypothetical form of dark energy, postulated as an explanation for the accelerating rate of expansion [6]. These theories, however, are entirely speculative as much as it is not clear what the physical nature of the dark energy should be. The tiny value of the cosmological constant represents one of the greatest problems in present day cosmology.

In spite of the ad hoc introduction of the hypothetical variables of DM and DE, a number of problems remain unsolved: the flatness or fine-tuning problem, the horizon problem and the magnetic monopole problem, for example, which cannot be explained within the frame of the standard model. A new hypothesis has therefore been invented in order to explain these puzzles.

6. One More Hypothesis: The Inflationary ΛCDM Model

Guth [7] proposed the inflationary theory, according to which the early universe had a brief period of extremely rapid expansion during which its diameter increased by a factor of perhaps 10^{50}. The inflationary scenario is capable of avoiding the flatness and horizon problems. Guth has shown that this exponential expansion automatically flattens matter in - homogeneities exactly to the critical density. If we further assume that the inflationary universe would have been small enough for light to come into equilibrium before inflation started, the horizon problem disappears.

7. The Magnetic Monopole Problem

Grand Unified Theories predict a number of heavy, stable particles that have not been observed in nature, for example the existence of magnetic monopoles, which are predicted to occur to the extent of being the primary constituent of the Universe. Not only is this not the case, but all searches for them have failed.

An Alternative Hypothesis in Order to Make the First One Work

A period of inflation occurring below the temperature at which magnetic monopoles can be produced would offer a possible resolution of this problem: monopoles would be separated from each other as the universe around them expands, potentially lowering their observed density by many orders of magnitude.

Cosmologist Martin Rees has commented: "Skeptics about exotic physics might not be hugely impressed by a theoretical argument to explain the absence of particles that are themselves only hypothetical. Preventive medicine can readily seem 100 percent effective against a disease that doesn't exist!" [8].

Hypotheses Bearing on Cosmology

The Cosmological Principle is the basic foundation of the standard model, and asserts that the universe is homogeneous and isotropic on a large scale. Temperature measurements show that the temperature of the CMB is uniform to one part in 10^5. Experimental proof of homogeneity and isotropy has also been presented using other methods. The validity of the Cosmological Principle can be taken for granted.

Table 1

Entities which have never been observed, and which cannot be proved experimentally

Hypothesis	Comment
Singularity	A single point of infinite mass and energy. The understanding of this lies beyond the human power of imagination.
Inflation	"I would not settle any bets on whether inflation really happened. I am not criticizing the theory; I simply mean that this is brave, pioneering work still to be tested" [9].
Negative pressure	This is a strange notion. It is unlikely that the zero point energy of the quantum vacuum plays any role in cosmology at all.
All parts of the universe began expanding simultaneously.	"How could all the different parts of the Universe began expanding simultaneously? Who gave the command?"[10].

Table 2

Provable but as yet not unproven

Hypothesis	Comment
Dark matter	Only indirect "evidence" exists, which possibly shows only that something is wrong with the Big Bang theory.
Dark energy	Its true nature, if it exists at all, is completely unknown. The cosmological constant is 120 orders of magnitude smaller.
The actual tiny value of the cosmological constant	No solution to this problem is in sight.
Hubble's constant represents recession velocity	The root of all evil. Expansion according to Equation (1) would require neither DM nor DE. A substantial minority of scientists dissent from the velocity interpretation of H_0.
Expansion hypothesis	Static models fit the observations better.
The physical laws as known from celestial mechanics are the same in the whole universe	"When we extrapolate the Inverse Square Law from the solar system where it was established, out to galaxies and clusters of galaxies, it simply never works. We cover up this scandal by professing to believe in Dark Matter, for which as much independent evidence exists as for the Emperor's New Clothes" [11].

As can be seen from Tables 1 and 2, nearly all of the problems of the Big Bang cosmology can only be solved by introducing new hypotheses which in important respects cannot be proved experimentally. New hypotheses are necessary to explain the consequences of the old hypotheses.

Nevertheless, the majority of astronomers are convinced that the inflationary ΛCDM model is the correct description of the beginning and evolution of the universe, and that the model needs only a few extensions and minor corrections. The publication of alternatives to this theory is almost impossible in scientific journals. "Even observations are now interpreted through this biased filter, judged right or wrong depending on whether or not they support the big bang [12]". This has also happened to the author, with the following reasoning being given for a refusal:

'The exponential slope of the Hubble Diagram [13, 14] is highly implausible. Several sources suggest that it (within the frame of the Big Bang theory) never can be the case.' 'Certain theories such as the Big Bang cosmology and the accelerated expansion of the universe have been considered as truth […] and even Nobel prizes have been awarded on it.' 'It all suggests that author has not performed the analysis with care.'

I can assure the reader that I carried out these analyses with great care; the results have also been confirmed by other authors [15-17].

I believe the reasoning for the refusal was not as obvious as that given by the Referee:

"The only direct evidence so far for a cosmological constant comes from the Hubble diagram of distant Type Ia supernovae, a method which relies on the standard candle hypothesis and on empirical corrections to the observed peak magnitudes on the basis of the observed decay times. Such corrections are essential for reducing the scatter in the data sufficiently so as to allow significant cosmological deductions. However there are systematic differences in the corrections made for the same objects by the two groups which raise legitimate concerns about their validity [18]". Further uncertainties are as follows.

An analysis of "the latest catalogue of 740 Type Ia supernovae (shows) that the evidence for accelerated expansion is, at most, what physicists call "three-sigma". "This is far short of the five-sigma standard required to claim a discovery of fundamental significance [19]". Another unexplained fact is that the light curves of gamma ray bursts do not show time dilation at all, and thus the velocity interpretation remains questionable.

As one can see, the concordance model is not as concordant as supposed by the Referee.

“Presently, it might be too early to consider the concordance model as definitely established, corroborated by independent probes [20]”.

The question therefore arises: what is the real status of the ΛCDM Big Bang cosmology? Presently, no final answer can be given to this question:

- Either the ΛCDM model is the biggest triumph of human imagination; or
- It is its biggest mistake, caused by a dogmatic adherence to a wrong paradigm, namely to the velocity interpretation of the cosmic redshift; a new proof in the history of cosmology that mathematics and physics cannot recognize the truth if the basic idea of the model is wrong.

Lastly, for purpose of correctness: The ΛCDM model does not only rest on postulates, hypotheses and ideas. There are a number of observations and experiments and an impressive theoretical background which are strong indications in favor of the Big Bang model; however, they do not prove it. We have many theories and hypotheses and many experimental results in favor of the Big Bang, but also many possibilities for explaining the same phenomenon in a different way [21-24]. Although the theory provides a straightforward explanation for the major problems of cosmology, the price is high: Big Bang cosmology rests on a never-ending number of hypotheses, the line between facts and faith is small and some of the cosmological hypotheses seem to have a quasi-religious stance.

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