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The big bang? Three questions without a reply

JEAN-CLAUDE PECKER

Collège de France, 3 rue d'Ulm, FR-75231, Paris Cedex 05, France. E-mail: j.c.pecker@wanadoo.fr

Putting the big bang in its historical perspective makes it appear as the result of a succession of random thinking, animated by new observations – although constrained by their reference frame – and that of concepts often frozen. It appeared first as the only solution able to account for the existing observations; with newer observations, it appears now just like the old Ptolemaïc system, to which Aristotelians, Platonians or Pythagorean of the Renaissance worked hard to add epicycles, and again new epicycles, against all the principles of simplicity claimed in their beginnings, in order to save the basic principles of the model.

We shall assume that the reader is somewhat familiar with the concept of the Big Bang; this metaphoric name designates the explosive origin of the Universe, perhaps identical with a Creation *ab nihilo*. Probably you have not the slightest doubt about it, so much has been claimed for the concept – through the media, through the popularizors of science, and also some distinguished scientists – as being generally accepted by the specialists, as a certainty without a doubt. For the average reader, the Big Bang is indeed a dogma. One would not conceive that the Universe could *not* be born from some Big Bang. Many good and reputable astronomers say so. Our purpose here is only to show that '*it ain't necessarily so*', as for the biblical events recalled in the lyric of Gerschwin's *Porgy and Bess.*

Introduction: Birth of the Big Bang

Actually, the idea of a world that was created at a certain time in the past permeates many religions. But this was by no means admitted generally during the golden age of the Greek philosophy. Plato, of course, introduced a Creator (the '*δεμιυργος*'), and his universe had indeed a beginning. But once created, it remains at it is, and Plato does not mention any evolution of it. Plato, in some of his views, had been strongly influenced by Pythagoras, and as with the Pythagorean, he was much impressed by the simple constructions allowed by elementary arithmetics or by geometry: the world created by God was ruled by simple numbers and figures. So were the motions of the Sun, Moon, and planets.

However, Aristotle believed in the opposite view, of an uncreated universe, eternal, infinite, and animated by unchanging motions. Astronomers, after him, from Antiquity to modern times, have been indeed working at understanding the structure, the motions, the dynamics of these motions, under the hypotheses of an infinite extension and of an infinite duration. Of course their ideas have evolved very much during that period, from a very limited geocentrism, to a reasonable heliocentrism, and to constructions enabling the understanding of the observed phenomena related to the motions of the Sun, of the Moon, and of the observable planets.

The idea that the World (we shall now say instead, the Universe, with a capital U) has indeed undergone some evolution began to be considered in the 18th century in a very limited way (Kant and Laplace), but it exploded during the 19th century (with ideas of the evolution of life: Lamarck, and Darwin) and in the 20th century (evolution of stars and of the Universe).

New discoveries in physics and new astrophysical observations then formed the basis of the Big Bang theories. The development of astrophysical spectroscopy led to the identification of lines of spectra of the stars, characteristic of the elements present in the stellar atmosphere, and provided information about the temperature and pressure at which they existed; and soon it was extended for the galaxies. It was noted that these lines were sometimes displaced in the spectrum with respect to the lines of the same element as observed in the laboratory. This was easily explained by the ‘Doppler–Fizeau effect’; the spectral lines of a star moving towards us are displaced to shorter wave-lengths, i.e. they are ‘blueshifted’; the spectral lines of a star receding from the observer are displaced to the higher wave-lengths, they are redshifted. Such spectral shifts are observed for example in the spectra of the two components of a double star, which are turning each around the other.

Vesto Slipher discovered (in the period 1912–1925) that the majority of close-by galaxies displayed a redshift, but that the fainter the brightness of the galaxy observed, the bigger the redshift. Henrietta Leavitt, had by then (1912) found a law linking the absolute brightness of a certain type of variable star, the ‘cepheids’, with the period of their variation, which was a few days. Therefore, measuring that period gave the absolute brightness of such a star, a comparison with its apparent brightness gave immediately its distance, or the distance of the galaxy containing that variable star. Relations other than that ‘period-luminosity’ law, but of a similar kind, were also established. These laws were exploited by Edwin Hubble, who extended Slipher’s measurements, and established in 1929 an empirical relation between the redshift and the distance. If one adopts the

Doppler interpretation of the redshift, the relation between the distance D and the velocity of recession V of the galaxy leads to what is called 'Hubble's law'; the number $H = V/D$ is the 'Hubble ratio', which is dimensionally the inverse of a time.

Hubble suggested a 'linear' law, the velocity being proportional strictly to the distance; H_o is then 'constant' and called 'Hubble's constant'. However, at about the same time, Lundmark, using the same data suggested instead a quadratic law, the redshift being proportional to the square of the distance. But further researches, going much beyond the Hubble's earlier data, have reached the conclusion that the Hubble's law is indeed linear, up to high values of the redshift and of the velocity of recession.

As time passed, more distant galaxies were observed, using new methods, to calibrate the distance. And in the same time, the derived value of H_o decreased drastically compared with the value obtained by Hubble, 530 km/s/Mpc. Now, the best value of H_o is around 65 km/s/Mpc. (The Megaparsec (Mpc) is a unit of distance used by astronomers; one Mpc is equal to one million 'parsecs', the parsec (pc) being equal to 3.26 light-years. One Mpc is equal to about 30 billions of billions kilometres, precisely 3.0857×10^{24} cm.)

The Universe, everywhere, thus appears as expanding; each galaxy goes away from any other one with a velocity proportional to their mutual distance. This expansion has no centre, it affects the whole Universe.

A natural step is to rewind the clock of time. If the Universe is now in expansion, and if this expansion has always been taking place at the same rate, it should imply that, at a certain time in the past, the Universe was condensed into one single point of the time-scale, with an infinite density everywhere. A simple computation, from the value of the Hubble constant presented above, fixes this 'Hubble time', or 'Hubble age' to be equal to about $1/H_o = 17$ billion years.

Of course, it is a gross simplification to call this is the 'age of the Universe': there is indeed no observational evidence allowing one to claim that the rate of expansion has been constant during the lifetime of the Universe.

It is at this point that General Relativity appears in the picture, although it was in existence much before the Hubble's papers. General Relativity was proposed by Einstein in 1915 as a set of dynamical equations determining the behaviour of physical systems; gravitational forces are imbedded, so-to-say, in the geometry of the Universe. In a region where massive objects are numerous, space has an important local 'curvature': masses shape the universal geometry, which in its turn determines the motions of the masses. These equations are more general than Newton's gravitational laws, they take into account the fact that interactions at a distance do not act instantaneously, they have to be propagated. One can apply them to any part of the Universe, or to the Universe itself. The solution of these equations is, in principle, and given some initial conditions, able to give an idea of the evolution of the whole Universe, and of all its massive components. But the solution of these equations is difficult. In order to simplify them, Einstein included a 'cosmological principle': that the Universe is well approximated by considering it to be homogeneous and isotropic (uniform in all directions); then the only unknown parameter is the uniform 'density of matter'. Note that the density of matter can also be measured by the 'average distance' between two points duly identified (two galaxies), or by a 'scale factor'. Einstein was driven by the idea that it was necessary to find a 'stationary universe' (of which the density is constant in time – a very Aristotelian Universe indeed). But universal Newtonian attraction alone would tend to push masses towards each other, making a collapsing universe. Therefore, Einstein had to introduce, a new term in the equations, a repulsive Λ-term (1917) in order to be able to find such a solution.

In the period 1922–1924, Alexander Friedman was not convinced that one should require the Universe to be stationary, so he deleted the Λ-term from the equations and found an infinite number of solutions of the equations, describing the evolution of the scale factor, or of the density, with time. From amongst all the universes compatible with the equations, the observed Hubble apparent expansion allowed the choice of one type of solution. And that type of solution reaches a 'singular point', at a time in the past more recent than the Hubble time, a 'singular point' in time, at which the density was infinite everywhere. This point is the 'origin' of the Universe. This time of infinite density, this singular point of the solution, defines the time of the 'Big Bang'; after this initial catastrophe, the density decreases very quickly, and the Universe explodes and expands.

A few years after Friedmann, Georges Lemaître found (1927), quite independently, a similar solution, which he called the 'primitive atom', describing the highly condensed state of the Universe at the time of the Big Bang.

Later, in the 1950s, George Gamow associated a very high temperature with the very high density of the Big Bang. This allowed further speculation on the physics of the Big Bang, and led to a great many developments of the theory, which we will not discuss here. Let us note only that the Big Bang constructed at that time was not found to be perfectly satisfactory in terms of new observations; it had to be modified and improved; and the models of 'standard' cosmology, which stemmed from the Big Bang hypothesis, now reached the claimed status of a 'precision cosmology', regularly improved i.e. repaired – but essentially stemming from the original Big Bang. Nowadays this standard cosmology is considered by most cosmologists as the only cosmology worth considering. However, several doubts must be expressed. We can describe them through, essentially, three questions, to which we shall devote the next part of this paper.

But we should face the fact that, at the present time, any new observational development is, as soon as published, used as an argument to sustain the Big Bang model, often at the expense of the introduction of some new parameters into its theoretical framework. For example, the observation of the background radiation, and of its fluctuations, the measurements of stellar and galactic abundances of the light chemical elements (hydrogen, deuterium, helium), the brightness of extragalactic supernovae, etc, legitimated over the Big Bang general framework the introduction of 'inflation', 'grand unification', 'supersymmetry', 'dark matter', 'obscure energy', etc. I am disturbed by this situation, which parallels, after all these centuries, the progressive Ptolemaic (and even Copernican) accumulation of epicycles over the original system of homocentric spheres of the Aristotelian cosmologists, as has been wisely noted by Jayant Narlikar. For that reason, I would like to drop the capital letters, and so, if we keep to the original hypothesis of Gamow, the name 'Big Bang', in its present (and evolutive) form has to be called the 'big bang'.

First question: is the Universe really in expansion?

Through its interpretation by the Doppler effect, the redshift was very early considered a measure of the velocity of recession of galaxies, and the Hubble constant a measure of the rate of expansion of the Universe. However, Hubble himself, and a noted relativist, Richard Tolman, always referred to the 'apparent' velocity of recession of galaxies. The great observer, Zwicky, in the 1950s, was reluctant to accept velocities of the order of a large fraction of the velocity of light for such huge objects as galaxies and he never accepted the Dopplerian interpretation. After all, we knew, at that time, of some redshifting mechanisms other than the Doppler effect, the Compton effect, the gravitational redshift, or even some form of the Raman effect, although all were too small to be a cause of the large redshifts in the spectra of galaxies. One therefore has to think of other interpretations of the redshift.

A first group of ideas was those of a 'tired light' mechanism: light, when travelling through space, interacts with the medium it goes through, perhaps through collisions with some particles, or through the interaction with the generalized gravitational field, and this leads to a loss of energy of the photons that is strictly proportional to the path length. That hypothesis (defended by Fritz Zwicky in the 1930s, then by Findlay-Freundlich and Max Born in the 1950s, then by the author, Jean-Pierre Vigier and collaborators, in the 1970s) is justified by the linearity of Hubble's law. However, it was not substantiated by any other independent laboratory experiment and therefore, it was not considered seriously.

Another type of hypothesis stemmed from the idea that the redshift could be just a geometrical property of the Universe. An extreme development of this was developed by Irving Segal in the 1970s; his 'chronogeometry' introduces two types of cosmical times, and leads to a quadratic law of redshift-distance, strongly supported by statistical evidence. This evidence was not generally accepted and Segal's theory is now mostly forgotten.

However, in the 1970s, a major discovery gave some weight to the idea that the redshift is indeed perhaps of a different nature. It was the discovery by Halton Arp (1971) of 'abnormal' redshifts, observed in the highly redshifted spectra of the 'quasars', often associated with a low redshift galaxy. The quasars are very active objects, strong radio and X-ray emitters, and differ clearly from ordinary quiet galaxies. The evidence was that one should at least accept the existence of two types of redshifts: one, 'cosmological', associated with the distance, another one, 'physical', associated with the nature of the source of radiation.

These observations, although attributed by some authors to some artefact (such as 'gravitational intensification', or 'gravitational lensing'), seem very convincing, and so numerous that they cannot easily be explained away. It can be concluded that there probably are some causes, other than the Doppler effect, for the large redshifts, but we are still ignorant of the physical explanation.

If that is so, the natural reaction is to assume that, if some redshifts are non-Dopplerian, one might as well admit that none of the cosmological redshifts is Dopplerian, and that Hubble's law is explained only by the fact that light is 'tired' by long travel; the light from the quasars being 'tired' because of originating and travelling in a very abnormal source of radiation.

Most cosmologists however still ignore the observations of Arp (and of his many followers); they claim the observations are due to some effect of the gravitational refraction, an interpretation that has never been successfully proven in the specific cases studied by Arp. The most daring of them admit that Arp's 'abnormal redshifts' are real, without generally even trying to understand them. However, apart from the abnormal redshifts, there exists for them a 'cosmological redshift' associated with expansion, which is strictly 'Dopplerian'. This is the position of both the 'standard cosmology', and of cosmologies such as the 'quasi-stationary cosmology', of which we shall speak in the next section.

In spite of the present lack of evidence for other effective processes of redshifting than the Doppler effect, I consider this first question, '*expanding or not expanding?*', as still an 'open' question, but for now, we should conclude, provisionally: '*expanding*'.

Second question: even if now expanding, cannot the Universe have been of an infinite duration in the past?

One should face the fact that, even if we admit the Dopplerian interpretation of the cosmological redshift, even if Hubble's law is valid, the non-uniqueness of the solutions of General Relativity equations leads naturally to the non-uniqueness in the description of the 'now-expanding Universe'.

In the 1960s, Hoyle, Bondi and Gold, who, as with Einstein, did 'like' the Aristotelian idea of a stationary un-created Universe, but admitted no other redshifting mechanism than the Doppler effect, suggested a stationary Universe, in permanent expansion, but where a 'continuous creation' of matter would everywhere compensate for the expansion, maintaining constant the density of matter. This model was not able to predict some observations, such as the background radiation of the sky, observed in the microwave range. Some physicists, who did not accept the metaphysical implications of any model, and who for that reason were suspicious of the Big Bang, found continuous creation no more acceptable *a priori* than a creation *ab nihilo*.

The idea was revitalized, in the 1990s by Hoyle, Burbidge and Narlikar, who proposed a '*Quasi Steady State Cosmology*' (1993). In this model, which uses the equations of General Relativity, the Universe oscillates between a state of maximum density (maximum, but not infinite), and a state of minimum density (minimum, but not zero). This model is able to predict, equally as well as the standard Big Bang cosmology, many observed properties that can be labelled 'cosmological': the background radiation, Hubble's linear law, the light element contents of the Universe, the fractal distribution of matter (in the observed universe). It introduces not a continuous creation of matter, but a 'local' creation of matter in local explosive events (as suggested earlier by Victor Ambarstumian), in which the 'young matter' behaves in a way that could explain the 'abnormal' high redshifts of the quasars and active galaxies, where these explosive events occur. This local creation of matter has, as a consequence, the property of increasing regularly the density of matter, from the epoch of a minimum density to the next, and from the epoch of a maximum density to the next. Astronomical tests of this model have been proposed, and they could be achieved in a not too distant future.

This theory is at present the only completely credible alternative to the standard cosmology, but is not accepted by the promoters of the standard cosmology, who prefer to accept the latter and correct it, step by step, in order to take into account the new observations, instead of changing radically their point of view. Their main argument is that, in an infinite duration model, entropy will have reached an equilibrium value, its maximum, and by then all the hydrogen should have been transformed into helium, hence at the present time we should not observe any hydrogen – if the past life of the Universe had been of an infinite duration.

One can reply that the quasi-steady-state model, because of the creation of matter, is acting as if decreasing the entropy of the Universe. One can also note that our Universe may have been in the past, or may become in the future, connected with some other 'universes', now entirely out, by nature, of any observational reach, however powerful the instrumentation. Most standard cosmologists still think that this argument is far from convincing.

However, I do not agree with them, and still consider the metaphysical question: '*created or uncreated?*' and the physical question: '*had the Universe an infinite duration or a finite one?*', as 'open' questions. And my present preference, would be to reply '*un-created, and of infinite duration*', i.e. without beginning and without end.

Third question: is then the standard model built on General Relativity so satisfactory?

Even if expanding, and having some definite origin in the past, is the 'standard model' derived from the General Relativity (GR) suitable to fit both these hypotheses and the observed facts? Is GR itself the last word of our vision of the physics of the Universe?

We should first realize that the present attitude of standard cosmology is to start the life of the Universe not by a singular set of conditions, but by a 'quantum' phase, of which little is known. Then, the GR equations would fail to give an answer, if not considerably modified. So let us consider only the post-quantum phases of the Universe. Let us remember that the GR introduced a space–time geometry of a high degree of generality, but the need to solve its equations in order to get a 'model' imposes on us a broad set of simplifying approximations.

First, the GR equations deal with a strict 'continuum', whereas we know that on a very small scale, quantum effects must modify the basic theory, in a way we still largely ignore. In addition, 'homogeneity' and 'isotropy' of the evolving Universe must be assumed, in order to solve the equations; but we see differences of more than 40 orders of magnitude between the density in neutron stars and that in the intergalactic medium. Moreover, the distribution of density is observed as 'fractal' in a very large volume, which expresses the fact that the 'average' density instead of being a universal number, at a certain epoch, is decreasing with the size of the volume in which it is determined. We have no way of knowing whether or not the average density will tend to a limit when the volume in which it is taken is that of the Universe itself; the notion of average density is indeed meaningless.

In addition to these basic difficulties in the standard use of GR, one can note that the flattening of the Sun is not what it should be under GR (although this statement is doubtful), not to mention the abnormal redshifts and abnormal refractions observed in the vicinity of the Sun.

Therefore, attempts have been made to propose theories that would encompass the GR (as the GR encompassed Newtonian dynamics), or to use it with a more realistic distribution of density.

One of these attempts by Brans and Dicke attracted attention for a while; its formulation introduces a new parameter, Ω, and when this parameter is equal to zero, the equations are exactly those of the GR. Unfortunately, the flattening of the Sun, which was the basic reason for Brans and Dicke's theory, can indeed be accounted for in the classical GR theory.

Another attempt is probably more promising. It is the cosmology of the 'scale relativity invariance' of Laurent Nottale. This theory introduces a sort of quantization of space–time, and uses a new way of treating the fractal space. The basic idea implies that (contrary to what is usually accepted) there is a deep unity, even a formal unity between the physical laws of different scales – quantic scale, classical physics scale and cosmological scale. This theory, which extends the principle of Einsteinian relativity, is in essence leading to an adaptation of the standard cosmology; as it stands, it does not differ from it, so far as the background radiation of the sky, or the abundances of light elements are concerned; but it could probably as well be adapted to the quasi-stationary cosmology.

Other transformations of the standard cosmology imply rather complex topological properties of space. Many other concepts can be added to the standard cosmology; for example, the idea that 'our universe' is only a part of the Universe; there are, non-observable now, other universes. This idea allows the entropy of the universe to decrease, as a 'local' property, thus not contradicting the Second Principle of Thermodynamics, which could not anymore be considered as needed for the cosmological models. An infinite duration becomes compatible with the evolution at large of the Universe, since there is no longer a one-way change of hydrogen into helium.

An important problem stems from the remark that the observable part of the Universe is made of ordinary matter. 'Antimatter' can be observed only in very special conditions, in large accelerators, and is unstable. Why should the Universe be dissymetrical, having a non-zero 'baryonic mass'? Several authors have tried to think of scenarios where the quantities of matter and antimatter formed from radiation were initially equal. Such is Souriau's model: for him, the Sun is located in one of the two halves of the Universe, that half being made of matter; the other half is made of antimatter; at the frontier (the 'equator' of the Universe), the quasars and antiquasars collide, emitting an enormous amount of energy in the form of gamma-rays, and disappearing in the annihilation consecutive to the collision. Souriau claimed to have proven the existence of such a gap in the space distribution of quasars, these very distant probes of the Universe, but there are doubts about his claim.

Others models suggest a variation in time of some 'universal' constants; and there are still many subtle but difficult theories, relativist, or 'post-relativist', on the market. I cannot here pay a proper credit to those, but they should certainly not be passed over that quickly. All these attempts to relocate the Big Bang in different contexts are fine, and valuable. But they do not however dissipate the wave of doubt that some of us hold.

So our last question stays also an ‘open’ question: the standard model, pushed hard by its promoters, certainly accounts for most of the observations, but it seems that it may have been pushed too far, with too many ‘necessary’ adjustments, it is too much *ad hoc* and contains too many adjusted parameters, and too much unknown physics to be fully satisfactory. Perhaps one should think first of keeping the GR as it is, and finding other solutions to its equations.

Conclusion

Where to look now? And what to think? Cosmology is not a science like others and it cannot be so. On one side, obviously, the future may bring new observational facts. They must fit the theory, or they must be fitted by the theory. But sometimes one feels that one is facing a new ‘procrustian’ bed, adding adjustments of the theory to improvements of the observations. Can we actually adjust the observations to an improvement of the physics? Probably so, just by selecting the facts that are fitting, and considering the facts which do not fit the theory as mere artefacts. At the present time, it would be wise to list observational tests that could be performed in the near future, remembering however that different theories may predict sometimes the same observed phenomenon.

We should also, in spite of their difficulty, attract some attention to the developments of new mathematical tools, such as ‘strings’ and ‘superstrings’. We do not know whether they are adapted to other observed facts or to laboratory physics. But, in spite of their obvious complexity, our minds should not be closed to these attempts to renovate theoretical physics.

But we should be very careful in that process. Physics has to be tested by repeatable experiments and by unambiguous observations. The mathematical coherence of a physical theory is not sufficient to justify it. Therefore, it is likely that we shall spend many years before reaching some satisfactory symbiosis between the theoretical attempts to produce new physics, and the wealth of astrophysical data.

So far, the modern visions of the big bang and of the expanding Universe seem convincing and are very seductive. However they are nothing, but a reasonable extrapolation of the observations, like the rival cosmologies, *and nothing more!*

A short bibliography

One of the best comprehensive and updated books on cosmologies is that of Jayant V. Narlikar, *An Introduction to Cosmology*, 3rd edn (Cambridge: Cambridge University Press, UK, 2002).

I have written on the history of the cosmological ideas: in French: *L’Univers exploré peu à peu expliqué* (Paris: Odile Jacob, 2003), and a version in English, of similar ideas, but quite differently written (less philosophical, more scientific): *Understanding the Heavens* (Heidelberg: Springer, 2001). These three books contain a very large specialized bibliography.

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About the Author

Jean-Claude Pecker is an emeritus Professor of Astrophysics at the Collège de France. He is a Member of the Académie des Sciences and has been Director of the Observatoire de Nice and Director of the Institut d'Astrophysique. He was Vice-President of the Academia Europaea 1989–1992.