The immense potential of comets as a major source for earth's waters is arrived after comparisons of deuterium/hydrogen (D/H) ratio in waters of our planet as well as in exogenous materials such as carbonaceous chondrites, comets, and gaseous planet like Jupiter[5]. Modelling studies of the evolution D/H in protosolar nebula have recognized an isotopic gradient – their ratio decreasing the closer they are to the sun and getting higher farther away. Based on this gradient, it is predicted that the D/H ratio for waters that condensed at 1 AU (where earth formed) should be close to the protosolar value of $\sim 80 \times 10^{-6}$. Earth, however, shows a ratio of $\sim 149 \times 10^{-6}$ which is close to the clay component within the carbonaceous chondrites. This suggests that the terrestrial waters must have been introduced from materials from the coldest regions of the solar system[22]. According to the proponents of this view, even though a small fraction of water may have come from water-rich bodies during earth's early accretion phase and hence indigenous, the main fraction was added exogenously by a few late giant-impactors[22]. A liberal calculation, however, puts this exogenous delivery around 10–15 per cent only and the rest may still be indigenous[8]. Present view is veering towards acceptance that earth's waters and atmosphere may have had mixed parentage – indigenous partly and exogenous in part through extra-terrestrial additions.

Many of the paradoxes and anomalies regarding the chemistry of earth, its waters and atmosphere have their roots in the first half billion year of earth's evolution when earth was still accreting through heterogeneous inputs of planetessimals, chondrites, asteroids, comets and the like. This was a turbulent phase of earth's evolution, a period notable for absence of reliable clues, many of which have been erased or reworked during earth's geological evolution. Apart from the question of earth's parentage, answers for many of the other events of earth's early history have also not been fully convincing and it appears explanations to these early events may have to come from astronomy rather than through geochemistry or geophysics. Hopefully, the ongoing unmanned research projects probing planets, near-earth asteroids, encounters with comets may help to demystify many aspects of earth's parentage and its chemistry.

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COMMENTARY

Cosmology – Facts and speculation*

N. Panchapakesan

Cosmologists are often in error but never in doubt.

— *Lev Landau*

Among scientists (specially physicists), there has been a discussion for a long time about how much of a science is cosmology. The difficulty earlier (before 1920s) was the absence of any observations and the stronghold of mythology. Even broad observed features were highly ambiguous. Only in the twentieth century was it realized that what were thought of as nebulae were really distant galaxies. In 1927, Hubble observed faraway galaxies and their velocities and formulated Hubble's law which says, 'The farther a galaxy is, the faster it is running away from us'. This gave rise to the model of the expanding universe now known as the 'Big Bang'. Almost forty years later, in 1965, the cosmic microwave background radiation (CMBR) was discovered accidentally. The non-uniformity or anisotropy of CMBR was discovered only in 1992. It is only in the last two

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decades that we have more detailed observations relevant to cosmology. The diffident and tentative claims of earlier cosmologists are now becoming rather tall. A recent claim that a standard model of cosmology, comparable to that in elementary particles, is taking shape[1] has made M. J. Disney from Cardiff, UK[2] ask some inconvenient questions. It may be worthwhile to ponder over the status of cosmology in the present time. Let us start by reviewing the generally accepted ideas in cosmology[3].

(i) Hubble's law is a plot of the velocity of galaxies against their distance. It is a straight line for nearby galaxies. The slope gives the Hubble parameter, which is related to the age of the universe. The departure of the plot from a straight line is a measure of the acceleration or deceleration of the expansion. The wide range of velocities (or the related red shifts of galaxies) needed for determination of acceleration has been possible in the last decade by use of supernovae as standard candles (sources of known luminosity).

(ii) Light elements like deuterium, tritium and helium were formed at the early stages of the universe. The conversion of about one quarter of the baryons (protons and neutrons) to helium and the rest remaining as hydrogen in the observed universe can be well understood as being due to cosmological nucleosynthesis. The abundance of deuterium plays a crucial role in determining the amount of baryonic matter in the universe. The precise value of abundance of deuterium is being measured with increasing accuracy, and will lead to more confident predictions.

(iii) CMBR is the relic of the early universe. Its spectrum is remarkably close to that of a blackbody of temperature of 2.7 K. The spatial or angular anisotropy of CMBR mirrors the anisotropy of the universe at the time when radiation stopped interacting with matter (at a time of a million years from big bang time $t = 0$). This anisotropy gives us very important information about the seeds which have grown into the local structure now seen in the universe. The CMBR is a natural consequence in the big bang model, but is rather difficult to accommodate in the steady state model, which thus resulted in the demise of the latter model. However, recently (1993), a modified quasi steady-state cosmology (QSSC)[4] has been proposed.

The cosmological nucleosynthesis was discussed by George Gamow in the forties[5]. At that time, his students, Alpher and Hermann[6], predicted CMBR with a temperature of about 5 K (close to the 1965 observation of 2.7 K). That the prediction did not lead to an immediate search for the relic radiation was due to the subject of cosmology being viewed with scepticism, and cosmologists not being sure of themselves. The developments following the discovery of CMBR have made cosmology come of age and made cosmologists confident (even overconfident as we shall see).

The evolution of the universe is given by differential equations provided by the general theory of relativity[3]. The initial conditions needed for their solution have been found by fitting the observations. The unusual nature of these initial conditions (like homogeneity, isotropy and flatness) is also now being attempted to be explained by the increasingly confident cosmologist. The emergence of gauge theories with broken symmetries leading to the electroweak theory of Salam and Weinberg gave rise to the exciting idea of inflationary scenario. The supercooling at the time of the symmetry-breaking phase transition (like the one which causes the unified electroweak theory to separate into electromagnetism and weak interaction) can cause an exponential expansion of the universe for a short period (called inflation). The inflationary expansion forms the whole universe from a small homogeneous and isotropic patch. The large amount of expansion leads to a very high degree of flatness. Quantum fluctuations produced during the supercooling stage can serve as seeds for the production of large-scale structure in the universe. This is an unanticipated bonus of the inflationary scenario.

Unfortunately, no viable model of inflation has emerged so far. Most models lead to very high inhomogeneity if conventional values of physical parameters are used. Alternatively, the small inhomogeneity required leads to parameters very finely tuned, negating the very purpose of inflationary models. In spite of such failures, the inflationary idea seems to hold strong attraction for cosmologists and continues to be discussed vigorously. Detailed analyses of the anisotropy seen in the CMBR seem to indicate that the universe is flat[7]. This is claimed as supporting the idea of inflation, forgetting that this was the motivation for and not a prediction of inflationary scenarios. It is possible that ideas of inflation may become viable and become part of cosmology in the future, but it is too premature to say anything definite at this stage. This makes one marvel and despair at the claims made on behalf of inflationary scenarios. One cannot avoid the feeling that the cosmological pendulum has swung from diffidence and scepticism to overconfidence and speculation.

Recently, Disney has advocated caution in accepting the tall claims made by cosmologists[2]. He even asks the question, 'Is cosmology a science?'. We have been recently asking ourselves in the country, 'Is astrology a science?'. More recently, Amartya Sen[8], the Nobel Prize-winning economist had tried to answer the question, 'Are social sciences really sciences'. Interestingly, Sen had tried to defend the inexact predictions of economics by referring to the inexactness in meteorology (in weather prediction) and in cosmology (in estimating the age of the universe). Disney points out that not only are observations in cosmology very few and scarce, but we cannot also have controlled experiments. Even the statistical methods available in astronomy are not available in cosmology, as we have only one universe. Further, one has to extrapolate physical laws to large distances and times. The inverse square law seems to fail when extended to galactic halos. This has been avoided by postulating 'dark matter' for which 'as much evidence exists as for the emperor's new clothes'[2]. Disney points out that cosmology can never be like the 'standard model of particle physics' (as claimed in ref. 1), as it can never have controlled experiments.

This criticism has provoked at least one well-known cosmologist, P. J. E. Peebles[9] (who can be called a high priest of cosmology in a non-derogatory sense) to respond. (Peebles along with Dicke, Rolle and Wilkinson, had started experiments for detecting CMBR in the early 1960s. After hearing Peeble's talk about this experiment in 1965, Penzias and Wilson, the actual discoverers, realized that the radiation noise, which they were unable to get rid of, was just CMBR[10].) Peebles accepts some of the criticisms about tall claims and has tried to summarize what has been really learnt in cosmology in recent times. He claims confidently that cosmologists have firmly established the foundations of our field. He is, however, appropriately modest in his claims for cosmology. The first, and strongest claim is 'abundant evidence that our universe is expanding and cooling'. He says this is the essence of the big bang theory. According to him, even the latest alternative version (QSSC mentioned earlier[4]) does not dispute this claim. He carefully avoids the word 'explosion', as according to him the big bang theory describes how our universe is evolving, NOT how it began.

Peebles is highly conservative about various claims made by other cosmologists. He feels the idea that 'universe expands as the general theory of relativity predicts' has still to be tested in a tight-enough fashion. About 'dark matter of exotic particles dominating galaxies', he feels that there is only indirect evidence and alternative theories are yet to be ruled out. He is even less sure of the evidence for cosmological constant (sometimes generalized and called dark energy). Finally, according to him, 'The idea that the universe grew out of inflation is inconclusive. It is elegant and a brave and pioneering work still to be tested'. A more detailed quotation may be justified in the context of criticism by some social scientists that science involves only creation of theory frames[11].

According to Peebles, 'One version of the deconstructionist picture of science as I read about it is that clever people make up internally consistent stories to fit agreed-upon conditions, and that another group could have made up another story, equally consistent, with an equally satisfactory fit to some similar or may be different set of agreed-upon conditions. Those of us who believe we have convincing evidence (that) physical science describes aspects of an objectively real world, even on scales very different from what we can hold in our hands, reply that our theories have been validated by agreement with tightly overconstrained and cross-checked empirical tests. Inflation, as we now understand it, can be adjusted to fit a broad range of possible empirical results. This situation is unnervingly close to the deconstructionist picture, unless we stipulate that inflation is a working hypothesis.'

This is a refreshingly different view from the tall claims made for the inflationary scenario. With such a reasonable claim, there is no difficulty in agreeing that, 'Cosmology was a real physical science decades ago, though with a meagre well-established centre. The big recent change has been the rate of addition to the established centre'. Researchers work far from the established centre, where there is a large uncertainty and facts are unknown. So, 'Is cosmology a science?'. The very existence of introspection and debate shows it is, unlike in the case of astrology or even some of the social sciences.

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Science and Society

Immediately after the formation of a "New Division" by the British Association for the Advancement of Science, whose ostensible object is to institute enquiries into the social relations of science, events on a stupendous scale occurred in central Europe whose impact on international affairs was such as to rock the whole fabric of civilization to its very foundation. The ardent supporters of the "New Division" maintained a solid silence which must have earned for science the obligation of politicians for not embarrassing their delicate and difficult negotiations. Manifestly the function of creating public opinion either in favour of or in opposition to the conduct of diplomatic relations has become the prerogative of the lay press and of the members of the parliamentary opposition. From the general attitude of the whole body of scientists during the recent crisis, it is to be inferred that they make a sharp distinction between social affairs and political problems and that while the former might constitute a legitimate sphere for their interventions, the latter had best be avoided. We doubt the existence of such a sharp demarcation between the social and political questions whose paths cross one another and in certain directions become interwoven, and it must be dreadfully pretentious to keep them