Part I

Observational facts relating to discrete sources

1

The state of cosmology

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In introducing the general topic of this meeting I am going to give a personal view. Only late in my professional career (∼1990) did I begin to work seriously in cosmology, though I had always followed with interest the various claims that progress was being made, and I even wrote a review of the state of affairs for *Nature* in 1971 entitled, "Was There Really a Big Bang?" (Burbidge 1971).

1 Introduction

For some years this period, starting in the 1990s, has been said to be the golden age of cosmology. Compared with the situation earlier, this is a fair judgement, since in the last decade or more there has been a tremendous increase in the number of people working in the field, and large sums of money have been invested in new methods of observation of the background radiation and of large numbers of galaxies and other discrete objects, often those with high redshifts. Another important ingredient is the renewed interest in cosmology taken by many theoretical physicists and experimental particle physicists.

With this expansion has come a great deal of new information, and a model for the Universe that almost everyone believes in. This in turn means that while there are many conferences on cosmology, the theme is almost always the same. This meeting will be different because some of its organizers have for a variety of reasons not followed the main stream. At the same time I hope that there will be a fair discussion of the conventional cosmological model.

In this introduction I want to make it clear why it is that some of us do not accept as the only starting point the usual model of an evolving universe starting with an initial creation process. The arguments against this approach are of two kinds. First there is the history, which shows that on several occasions in the early work assumptions were made that would lead to the observed answers, when alternatives were possible i.e., there have been very few real predictions, and second, the modern situation in which not all of the data are taken into account. This being the case it is extravagant and entirely premature to make the kind of claims that are now being made (cf. Spergel *et al*. 2003) for a standard model.

2 The expansion of the Universe

The major discovery was the redshift–apparent magnitude relation for nearby galaxies by Hubble in 1929 (Hubble 1929). This was immediately interpreted as direct observational evidence for an expanding universe of the Lemaitre–Friedmann type, meaning that this interpretation agrees with the expanding solution of Einstein's equations. By 1930 everyone accepted that the Universe is expanding. Reversal of the time axis of the expansion then leads to the conclusion that there was a finite origin for the Universe, which Lemaitre in 1936 originally described as the "Primeval Atom."

3 Nucleosynthesis and the cosmic microwave background

There were no convincing physical investigations of the early state of this Primeval Atom until the late 1940s, when a group of leading physicists including Rudolf Peierls, Enrico Fermi, Edward Teller, Maria Meyer, George Gamow, and his colleagues Ralph Alpher and Robert Herman and others made the assumption that it was at that very early epoch that the chemical elements were synthesized. Gamow in 1946 had originally speculated that the electron degeneracy in the early Universe would more than compensate for the mass difference between the neutron and a proton plus electron. Thus he concluded that the matter at the beginning would be a single neutron lump, so that the synthesis of the chemical elements out of this lump could be a verification of the Friedmann model. However, the problems of nucleosynthesis immediately encountered were, first, that there is no stable mass at $A = 5$ or 8 so that the build-up cannot go beyond D, ^{3}He, ^{4}He, and ^{7}Li. Second, a radiation field together with neutrons, protons, and electrons leads to more complications, which were discussed by Gamow, Alpher, and Herman. The other leading physicists gave up the problem when they realized that the bulk of the chemical elements could not be made in this way.

It was also realized in this period that the bulk of the known ^{4}He, approximately 25–30% by mass, could not have been made in the stars seen in the galaxies. The problem was that using the known luminosities of galaxies and the time scale for the Universe, which was then thought to be 2×10^9 years, very little helium would have been made. Thus it was concluded that the helium must have originated in primordial nucleosynthesis. This required that the energy density of radiation in the early Universe had to be very large. Until then, the reverse had always been assumed in Friedmann models. In such models S(t) (the scale factor) $\propto t^{1/2}$ and $T_9 = \text{const.}\ t^{-1/2}$. The next step was completely ad hoc. The mass density of stable non-relativistic particles, ρ_b, explicitly neutrons and protons in the theory of 1950, decreases with the expansion as S^{-3} or $t^{-3/2}$. Alpher and Herman put the density $\rho_b = 1.70 \times 10^{-2}\, t^{-3/2}\ \text{gm}^{-3}$. But there is nothing in the theory that fixes the value of this numerical coefficient. It is adopted to make things come out right, i.e., to make the calculated value of Y agree with the observed value. This is why the big-bang theory cannot be claimed to explain the microwave background or to explain a cosmic helium value close to 0.25. It is only an axiom of modern big-bang cosmology, and the supposed explanation of the microwave background is a restatement of that axiom. Thus in no sense did the big-bang theory predict the microwave background.[1] This would only be true if the factor 1.7×10^{-2} is called a prediction. If we eliminate t between the relations given above we find that

$$\rho_b = 1.51 \times 10^{-32}\, T^3 \tag{1}$$

which can be rounded off to $\rho_b \approx 10^{-32}\, T^3\ \text{gm cm}^{-3}$. Alpher and Herman put the mass density of the Universe as $\rho_b = 10^{-30} \text{gm cm}^{-3}$ and thus concluded that T must be about 5 K. Ten years later, when the Hubble constant had been further reduced, it appeared that $\rho_b \simeq 10^{-29} \text{gm cm}^{-3}$, and then both Gamow and Dicke suggested that $T \simeq 15$ K. Of course these were gross overestimates.

What none of the physicists throughout this period was aware of was that in 1941 McKellar (1941) had determined the temperature of the interstellar radiation from the spectra of the interstellar lines due to the molecules CH and CH^+, which Adams and later McKellar had detected in the spectra of stars. McKellar showed that if the radiation has black-body form, 1.8 K $< T <$ 3.4 K, which is in remarkable agreement with what was found later. McKellar stated the following

"Adams has kindly communicated to the writer his estimate of the relative intensity, in the spectrum of ξ Ophiuchi, of the $\lambda R(0)$ interstellar line of the $\lambda 3883$ CN band and the $\lambda 3874.00$, R(1) line, as 5 to 1. $B_0 J''(J''+1) + \ldots$ has the value 0 and 3.78 cm^{-1} for the 0 and 1 rotational states and for the two lines R(0) and R(1) the values of the intensity factor i are, respectively, 2 and 4. Thus from (3) we find, for the region of space where the CN absorption takes place, the "rotational" temperature,

$$T = 2.3\ K.$$

If the estimate of the intensity of R(0)/R(1) were off by 100 per cent, this value of the "rotational" temperature would not be changed greatly, R(0)/R(1) = 2.5, giving T = 3.4 K and R(0)/R(1) = 10 giving T = 1.8 K."

[1] For Y = 0.24, which is closer to the preferred current value, the constant η is now close to 4.5×10^{-2}.

When, in 1965, Penzias and Wilson reported that they had directly detected the radiation (Penzias and Wilson 1965) and later Mather *et al*. (1990, 1994) showed that the radiation is of almost perfect black-body form with $T = 2.726\,\mathrm{K}$, they were richly rewarded. What I want to stress here is that while the black-body nature of the radiation was predicted by the big-bang theory, the numerical value of the temperature was not, and cannot be (see Turner 1993), and since McKellar had already measured it, admittedly indirectly, it is a moot point as to whether the 1965 event truly was a major discovery. (If someone has already discovered a new phenomenon and published it, but the people most interested are unaware of the earlier discovery, how should credit be apportioned?) In truth no prediction was involved. But the psychological effect based on mistaken ideas concerning the prediction and discovery is one of the major reasons why the big bang theory is believed.

What is now being done is to put the observed temperature in Equation (1) and derive a value for ρ_b. This is then compared with the value obtained from the nucleosynthesis calculations and observations involving D, ^{3}He, and ^{4}He. Very good agreements can be reached between theory and observation for $\rho \sim 3 \times 10^{-31}\,\mathrm{gm\,cm^{-3}}$; so this is now called the observed baryonic mass fraction in the Universe. This is a clear plus for the big-bang cosmology. However, since the closure density in the big-bang model $3H_o^2/8\pi G$ is about $6.8 \times 10^{-30}\,\mathrm{gm\,cm^{-3}}$ (for $H_o = 60\,\mathrm{km\,s^{-1}\,Mpc^{-1}}$) this is only about 5% of the closure density.

While this discrepancy has been known for ~30 years, it is only in the last few years that this "missing" mass energy has been claimed first to be cold dark matter (CDM) and more recently cold dark matter and dark energy (Λ CDM).

An elaborate "theory" (more appropriately a "scenario") of galaxy formation then rests on this belief that this missing mass is real, because only if CDM exists in large measure is it possible to simulate galaxy formation at all. This is a classical example of "The Emperor has no clothes" syndrome. While a great deal of energy and money is being devoted by particle physicists to searches for the WIMPS, which could conceivably be the basis for the dark matter, nothing has been found so far (cf. Seife, 2004).

But, of course, none of this is necessary if we go back to the original observation of the ^{4}He/H ratio and take the position that the observed ratio is the result of hydrogen burning in stars. Then, of course, the whole of the mass must be baryonic. This leads us to one final point. If hydrogen burning was responsible for this ratio, an estimate can be made directly from observation of the energy released in this process. The mass density in the Universe can be determined from the masses of galaxies derived from their rotation curves and/or the velocity dispersion of the stars in galaxies, or of the galaxies in clusters. The virial for both individual galaxies and clusters is assumed to hold, so that in making this estimate we are assuming that some of the mass is dark. Putting in observed values for the space density of galaxies and a range of values of *M/L*, and a Hubble constant of 60 km s^{-1} Mpc^{-1} and supposing that the ^{4}He/H ratio is 0.24, we obtain an energy density of the radiation 4.5×10^{-13} erg cm^{-3}. This energy will initially be released in hard photons (UV radiation) but ultimately, according to thermodynamic arguments, it will be degraded to black-body radiation with $T \simeq 2.75$ K. This is remarkably close to the measured value of 2.726 K. This is either a pure coincidence, as it must be for those who believe in the big bang, or else it tells us that hydrogen burning was originally responsible for the Cosmic Microwave Background (CMB). In the Quasi-Steady-State Cosmology (QSSC) it is argued that it is due to hydrogen burning in the newly created galaxies and that intergalactic dust is responsible for the degradation to thermal energy.

While this agreement was mentioned in one or two earlier papers (cf. Fowler, Wagoner, and Hoyle 1967) it was not described in detail until 1998 when Hoyle and I managed to get it published in the *Astrophysi. J.* (Burbidge and Hoyle 1998). The paper was earlier rejected by *Phys. Rev. Lett.*, whose referees were strong proponents of the big bang. In our paper we showed that it was possible to explain the origin of all of the isotopes including D and ^{3}He in stars. D is probably built up in stellar flares on the surfaces of stars and partly destroyed by mixing in stellar interiors. An observational fact following from this hypothesis is that it predicts the D/H will be variable from one place in the galaxy to another, from galaxy to galaxy, and from QSO to QSO. But there really is no need to invoke a big bang.

Since none of the observations just described require this, what are the alternatives? Since the universe *is* expanding we can consider as possibilities a steady-state universe, which remains unchanged, or a cyclic universe with a cycle period of $\sim$20 Gyr. Here we omit discussion of Milne's kinematic cosmology, though it should not be forgotten that Milne raised the problem of the particle horizon, in the classical big-bang picture, and this is only claimed to be resolved now by recourse to an inflationary period.

It is natural that what came next was the classical steady-state universe of Bondi and Gold (1948) and Hoyle (1948).

4 The steady-state universe

The basic idea is that the Universe is not evolving. Thus matter (hydrogen) must be spontaneously created at a rate determined by the expansion. Bondi and Gold (1948) used as the basis for the theory what they called the perfect cosmological principle. Hoyle (1948) obtained the same model by generalization of Einstein's theory allowing for a repulsive term in the strong field regime (the C field) corresponding to creation (cf. Hoyle and Narlikar 1964, 1966). The steady-state theory was given quite a hostile reception as can be seen from an appraisal of the ways in which the various observational tests of the theory were handled (cf. Dingle 1953; Hoyle 1969; Hoyle *et al.* 2000, Chapter 7).

I believe that much of the prejudice in modern cosmology began at this time. In general the observers did not like the steady-state theory, although several of the pieces of observational evidence against it were shown later to be false. My good friend Allan Sandage has always insisted that some of his colleagues at Mount Wilson and Palomar were from its inception convinced that the steady state must be wrong, because they already had good evidence for evolution. Overall, one has the impression that most people liked the idea that there was a beginning, and that evidence for evolution would ultimately be detected. The general view was that all of the galaxies are old with ages comparable to H_0^{-1}. Thus, for example, evidence for young galaxies with ages $\ll H_0^{-1}$ (cf. Burbidge, Burbidge, and Hoyle 1963) was immediately disputed (Sandage 1963), so fast indeed, that the rebuttal paper of Sandage was published ahead of the paper by Burbidge *et al*. (was the editor, a good friend of all of us, showing his prejudice?).

5 The acceleration

There was one clear-cut prediction from the steady-state theory. This was that the expansion of the Universe would tend to accelerate (due to the creation process) rather than decelerate, as it must do in all Friedmann models without a cosmological constant (cf. Hoyle and Sandage 1956). Thus many claims were made from 1950 onwards that the observations showed that the Universe is decelerating, until by the 1980s it was finally admitted that the uncertainties in the observational methods being used were so great that it was impossible to decide.

Much more recently, starting in 1998, work using supernovae of Type Ia as standard candles, which can be detected at high redshifts, was announced by Perlmutter, Riess, and their colleagues (Perlmutter *et al*. 1999; Riess *et al*. 1998). They showed fairly conclusively, initially, with measurements out to $z \simeq 0.6$ that the Universe *is* accelerating. This being the case, there are two different cosmological scenarios that can explain it. The first is to insert a positive cosmological constant into the usual Friedmann models. The second is to remember that the classical steady-state theory *predicted* (cf. Hoyle and Sandage 1956) this result and the modified steady state (the QSSC) also predicted that the Universe would be accelerating (Hoyle *et al*. 1993, 2000). However, in reporting this result the observers once again showed their prejudice. Instead of at least stating that their result was qualitatively what had been predicted by the classical steady-state model and the quasi-steady-state cosmology, as is normally done in announcing a new observational result, and then going on to interpret their data in terms of a Friedmann model with a positive cosmological constant, they simply made the claim that they had demonstrated the reality of that model, as though that was the only way to go. And, of course, in doing this they were followed by the community who were equally ignorant or biased, or both, though attempts to clarify the situation (cf. Narlikar *et al*. 2002) have been published.

6 Driven by the cosmic microwave background (CMB) and the NASA value of H_o

Since the direct discovery of photons from the CMB by Penzias and Wilson in 1965, and the mistaken belief by many that this was the fulfillment of a prediction by Gamow and his colleagues (though they were undoubtedly short-changed when it came to recognition), the standard model largely buttressed by this CMB "discovery" took over. It was generally *assumed*[2] before it was established that the radiation would have black-body form (cf. the continuous discussion of "*relict*" radiation by the school of Zel'dovich), as indeed had been predicted by Gamow *et al*., provided it was generated in the big bang, and when it was finally showed by Mather *et al*. (1990, 1994) that the radiation has a beautiful black-body form over a wide range of wavelengths the triumph was complete. The result was cheered at the meeting when it was first announced (I was the chairman of the session of the AAS meeting at which the announcement was made).

For nearly all cosmologists this was thought to be the death knell of the steady-state model and any of its improvements (which we were working on at the time). The idea that such a background spectrum could be obtained from many discrete sources appeared to be much too farfetched, though we have now shown that it is entirely possible (Hoyle *et al*. 2000). And in many ways what was more important, the CMB had shown how homogeneous and isotropic this component of the Universe is. But a serious question that was still unanswered was to understand how the matter component can also show the same effect on the large scale, i.e., homogeneity and isotropy, if galaxies first condensed from quantum fluctuations in a very early universe, when conditions prevailed such that objects were not able to communicate with each other soon after the beginning.

The way out of this problem was to invoke *inflation*, proposed by Guth (1981) and Linde (1982, 1983). The main point that I want to make here is not that inflation is not a good idea. It *is*, but it is *not a paradigm* (cf. Peebles 1993). It is yet another idea *invented* to explain what we see, like the numerical value of the initial baryon-to-photon ratio and the existence of non-baryonic matter. Inflation has no basis in fundamental theory. Given all three of these assumptions we can make a plausible

[2] Preliminary observations from rockets suggesting that the background radiation was not of black-body form were widely discredited by theorists who had already made up their minds.

model that will fit the observations. *Without them we cannot*. But this is how big-bang cosmology or, if you like, evolutionary cosmology has progressed. The most recent observational programs are devoted to fitting together more and more of the details based on a series of assumptions chosen to make the original model work.

Undoubtedly the most impressive work of late on models of the Universe has been the most recent analysis of the CMB based on the WMAP observations. Spergel *et al*. (2003) have shown that assuming a model in which the Universe is flat with a large cosmological constant Λ, in which galaxy formation was started by nearly scale invariant adiabatic Gaussian fluctuations, they can fit the WMAP data very well with other parameters such as the Hubble constant and the D/H ratio in high redshift QSOs.

The agreement between the model calculations of the acoustic fluctuations in the CMB due to matter fluctuations out to the third peak expected is particularly impressive, so that there now is considerable interest and belief in this latest "cosmological concordance" model.

However, if we restrict ourselves to observational quantities that are not based on any assumptions other than that the Universe is expanding, the greatest discrepancy between model parameters chosen and observations probably comes from the Hubble constant, which Spergel *et al*. have used. They have claimed that this best-fit model is obtained when $H_o = 71\,\mathrm{km\,s^{-1}\,Mpc^{-1}}$, almost exactly the same as the value claimed to be correct by the group working with the Hubble Space Telescope (HST) and called the HST Key Project (Freedman *et al*. 2001). The difficulty with this is that this value of H_o may be much too high. Sandage and Tammann, the most experienced workers in the field, have since 1974 argued that a value close to $50\,\mathrm{km\,s^{-1}}$, $\mathrm{Mpc^{-1}}$ is a much better choice (for a detailed discussion see Hoyle *et al*. 2000, Chapter 4). Over the last few years Sandage and Tammann have competed directly with the other group, also using the HST (Tammann *et al*. 2002), but for reasons much more to do with NASA's approach to public relations than to science, all of the publicity and attention has been given to the results and the personalities of Freedman *et al.* When we made a careful study of all of the data available up to 1999 (Hoyle *et al*. 2000) we concluded that the best value is $H_o = 56$–$58\,\mathrm{km\,s^{-1}\,Mpc^{-1}}$. Sandage and Tammann and their colleagues in their most recent work (Parodi *et al*. 2000; Tammann; et al., 2002) have obtained a value for $H_o = 58.5\,\mathrm{km\,s^{-1}\,Mpc^{-1}}$.

There is no doubt that the popularity of the higher value of H_o has much more to do with the sociology of astronomy than to science. In this case the origin of this belief can be dated rather precisely, to May 25, 1999, when NASA held a press conference in Washington to announce, as they modestly put it, that the search for the Holy Grail of cosmology was over.[3] The research team working on what was called the Hubble Space Telescope Key Project claimed they had finally solved one of the

[3] (Ref. *New York Times Magazine* July 25, 1999). The article is entitled "The Loneliness of the Long-Distance Cosmologist," and it is not a very nice article about Allan Sandage.

original mysteries – the age of the Universe. Sandage and his team were barred from attending or speaking at this press conference. The press conference was followed up by a similar announcement to a very large group at an AAS meeting in Chicago, this time by Robert Kennicutt, a Key team leader. He was more circumspect and mentioned Sandage's and Tammann's work. Kennicutt's announcement was also widely publicized, as was the work on the microwave background mentioned earlier.

How sensitive is the model to the value of H_o that is put into the calculations?

Recently Blanchard *et al*. (2003) have tested whether or not a cosmological constant is really required by these observations of the CMB and large scale structure. They find that it is not, provided that the value of the Hubble constant is 46 km s^{-1} Mpc^{-1}, a value that is certainly compatible with the work of Sandage and Tammann. Other quite small changes in other parameters are required. Then we are back to an Einstein–de Sitter model. But then we have to deal with the evidence for acceleration described earlier, because it was this evidence that led the community to do an about turn soon after about 1998 and start using a positive cosmological constant.

Five years after the first evidence for acceleration and hence the presence of a positive cosmological constant "dark energy" was claimed, the picture has become more complicated. Many more SN Ia redshifts have been obtained out to redshifts $z \sim 1.5$ (cf. Barris *et al*. 2004; Riess *et al*. 2004). While it is still claimed that the work shows that there is dark energy and dark matter, it is suggested that at a redshift of about 0.5 there was a transition between acceleration and deceleration (a cosmic jerk). It also appears that a model with no cosmological constant, in which the effect is due to dust that is replenished at the same rate as it is diluted by the expansion, could also explain the observations (Riess *et al*. 2004).

By showing the way that a standard model has evolved (always starting with a big bang), I hope that by now that I have provided enough evidence for a reasonable person to conclude that there is no particularly compelling reason why one should so strongly favor a standard model Universe starting with a beginning rather than an alternative approach, apart from the fact that it is always easier to agree with the majority rather than to disagree. This sociological effect turns out to be actually extremely powerful in practice, because as time has gone on young cosmologists have found that if they maintain the status quo they stand a much better chance of getting financial support, observational facilities, and academic positions, and can get their (unobjectionable) papers published.

7 Explosive phenomena and the alternative cosmological approach

Starting in the 1950s the first radio galaxies were identified, and it became clear that they are extremely powerful energy sources often emitting energies of at least 10^{60} ergs ($\simeq 10^6\ M_\odot$) in the form of relativistic particles and magnetic flux filling