MODERN COSMOLOGY: SCIENCE OR FOLK TALE?

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Abstract:

In a survey for non-astrophysicists we compare the number of independent measurements which support Big Bang Cosmology, with the number of auxiliary hypotheses such as Dark Matter, Dark Energy and Inflation, and their associated free parameters, needed to shore it up. We find such parameters still outnumber the relevant observations, with no real sign of an improving trend over time. Precision, which is improving, doesn't necessarily guarantee the soundness of the interpretation. Non-cosmologists are thus entitled to be sceptical of such a weakly supported superstructure, which is currently composed of 5 separate theories piled on top of one another.

How could one find an answer?

It appears that everybody is interested in Cosmology. Every one of the more than 60 separate cultures studied by anthropologists (1) were found to have several common characteristics including: " …..faith healing, luck superstitions, propitiation of supernatural beings,…..and a cosmology…...". Apparently, to be human is to care how the physical world came to be, whether it has boundaries and what is to become of it. Modern cosmology is a highly sophisticated subject funded by governments with hundreds of millions of dollars a year . It is unquestionably interesting but is it, even in its modern guise, convincing?

The modern paradigm of cosmology has it that the cosmos is expanding out of an early dense state and that by looking outward in space we can, thanks to the finite speed of light, look back to much earlier epochs when the universe was comparatively dense and young. This 'Big Bang Cosmology (BBC)', owes much to two accidental discoveries: of redshifts in the spectra of distant nebulae by astronomers (~ 1920); and of an omnipresent background of microwave noise by radio engineers (1965) which is believed to be the remnant of Cosmic Background Radiation (CBR) from a hot and distant past. Set in the theoretical framework of General Relativity, Einstein's theory of gravitation , which is based on the idea that mass can curve Space-Time, such observations lead to a model which makes predictions and can be tested by further observations. Of late there has been much excitement over precision observations of the CBR and the discovery of very distant galaxies of great antiquity. There is even talk of a 'Concordance Model' in which all of the observations have come together to paint a coherent picture of how the universe must be (2,3).

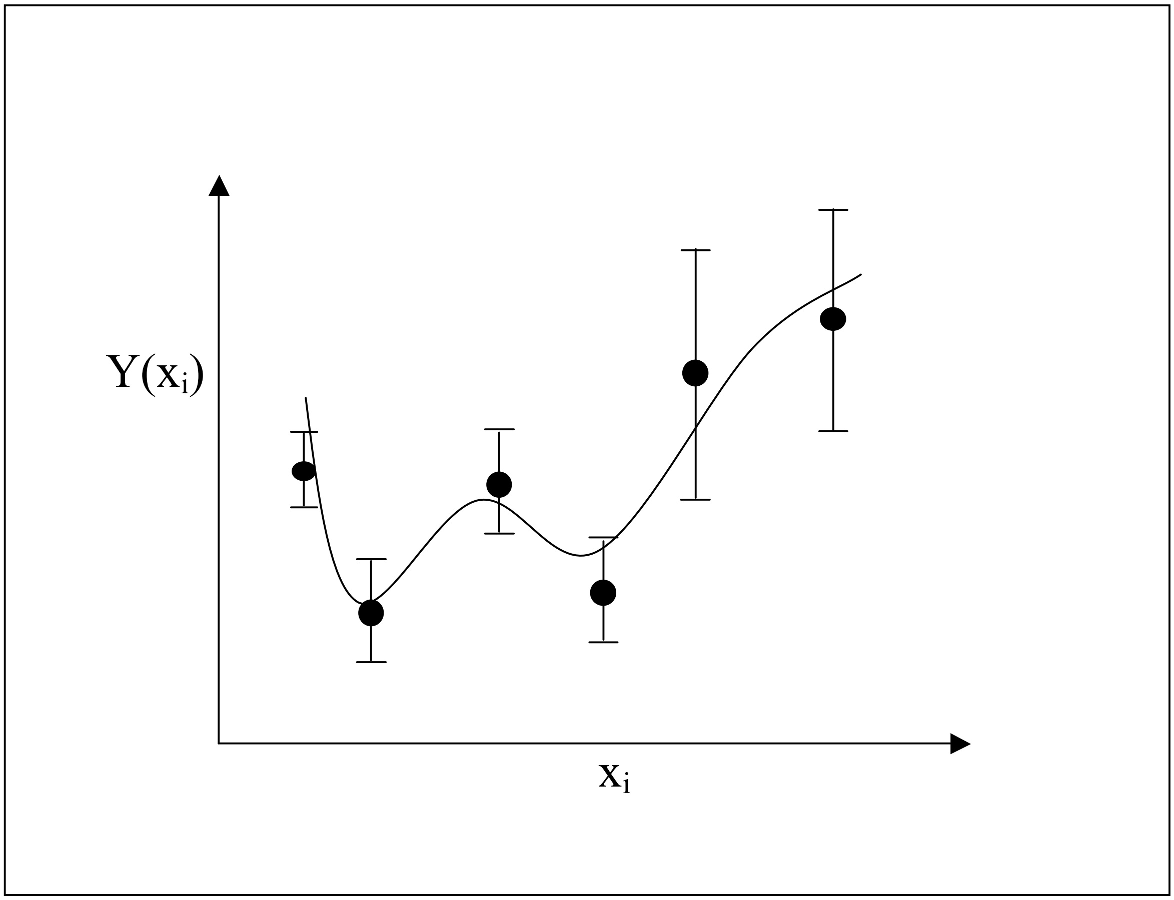
It is true that the modern subject has taken a turn for the better, if only because observers can now build instruments to deliberately test out cosmological ideas where, in the past, cosmologists could only wait for serendipitous evidence to turn up. On the other hand, in order to explain some of the surprising new observations, theoreticians have had to conjure up heroic and insubstantial notions such as 'Dark Matter' and 'Dark Energy' which supposedly overwhelm, by a hundred to one, the 'ordinary' universe we can actually detect. Interested laymen are bound to ask whether we should be more impressed by the new observations, or more dismayed by the theoretical djinns which have been conjured up to explain them.

Our limited aim here is to discuss this dilemma by looking at the development of cosmology over the past century in order to compare the growing number of independent relevant observations on the one hand, with the number of (also growing) separate hypotheses or "Free Parameters" which have had to be introduced to explain them. Without having to understand the complex astrophysics one can still ask, at an epistemological level, if – as you would expect of a maturing science – the number of relevant independent measurements has overtaken and comfortably passed the number of free parameters needed to fit them. We do so because we believe a discussion at this level can be appreciated by scientists from very different fields – and indeed by all who are interested in the empirical approach. Lacking any such discussion the layman has little option but to believe experts who may be far too committed to supply objective advice. For a more technical critique of modern cosmology see (4).

In a robust astrophysical field such as stellar structure there will be many more confirmatory observations than free parameters. In contemporary cosmology this turns out not to be the case. Indeed, as we shall see, the number of free parameters probably exceeds the number of relevant independent measurements, as it has done throughout history, with no sign of convergence between the two. Just because professionals cling to such a flimsy theory, there being no other within their current grasp, need not discourage the rest of us from being a good deal more detached.

The scientific approach to cosmology.

Our starting point is a toy model of the scientific approach as it is applied in the physical sciences. On the one hand experimentalists make observations with an estimated degree of uncertainty or 'error'. On the other theorists devise explanations or models to



Caption: A toy description of the methodology used in physical sciences. A theory should produce a mathematical curve which fits through the relevant observations, where $y(x_i)$ is a measurement, with error bars, of the observable quantity x_i. The worse the fit the less credible the hypothetical model is. The reverse is however not necessarily true. A model with enough 'latitude', i.e. with enough 'free parameters' i.e. parameters which can be chosen at will, can be made to fit practically any measurements. The theory will only be significant, i.e. likely to be true, if the number of its free parameters is comfortably less than the number of observations it has to fit. The need to introduce new free parameters to fit new observations is not the sign of a robust theory. On the contrary.

fit the observations as they exist at the time. Such a theoretical model is expected to generate a mathematical curve which matches the observations as well as possible(Fig.1). The credence we grant to a theory depends to a great extent, though not entirely, on the 'goodness of fit' between the theoretical curve and the available observations.

It is of course true that a sufficiently complicated mathematical curve can *always* be manufactured to fit any number of observations perfectly. For instance if the curve had the 'polynomial' form:

$$y(x) = a_0x_0 + a_1x_1 + a_2x_2^2 + a_3............+ a_{12}x_{12}^{12}$$

where $y(x_i)$ is the measured value of the physical quantity x_i, and the a_i s are constants , or 'free parameters' (FPs henceforth) to be chosen , then if we choose a polynomial with say 13 terms as above, we could always, by choosing the 13 FPs a_i appropriately, get a *perfect* mathematical fit of $y(x_i)$ to 13 independent observations x_i. Since almost any theory with the same number of FPs would make the same perfect fit, the observations lend no credence whatever to any of them. This is where the simplicity or 'parsimony' of a theory comes in (5) : of the theories which match the observations, the simplest, i.e. the one with the lowest number of FPs, is generally to be preferred. Why so? Because the probability of a curve with a smaller number of FPs fitting a larger number of independent observations *by chance* is obviously smaller. If there is such a good fit then the fit must be ascribed to something other than chance, i.e. to the probability that the theory behind that curve is actually true of the physical world. A high degree of such probability, a "high significance" in other words, is what the empirical scientist is hoping to find.

In practice observation and theory usually march forward side by side. Observers make new observations, or better ones (i.e. with smaller errors), both of which reduce the probability of a *chance* fit between the theory and the new observations. In parallel, theorists are modifying existing models or introducing new ones, which may have more or less FPs. Both sides are, or should be, seeking to improve the significance of the fit to a point where further work seems unnecessary.

A short history of scientific cosmology . Since our main section will be employed in thus counting FPs and measurements, without attending much to their meaning, we here preface it with the briefest précis of the cosmological background.

Scientific cosmology began with Kepler (1610) who recognised that a space filled with stars could not go on for ever, for that would imply a burning sky instead of the dark one we have. Three centuries later Einstein realised that his theory of General Relativity (GR) implied that matter and energy could curve the space-time structure of the universe as a whole; that one could, for instance, imagine a finite universe – and yet one which is everywhere equivalent i.e. with no centre and no edges (1917) . This idea was philosophically attractive for it potentially removed the need to worry about the boundaries. Unfortunately (or so Einstein thought of it then) GR implied that the universe would, because of gravity, either have to collapse or expand. So he found room (1921) for a new FP, the so called "Cosmological Constant" Ω_Λ, a sort of arbitrary anti-gravity, to put a stop to all that. Ironically the observers Slipher and Hubble, who were recording the first spectra of faint nebulae at the same time, found that they were dramatically 'redshifted' – hinting that perhaps the cosmos was expanding after all (though the Expansion hypothesis remained contentious for 30 years and Hubble himself died in 1955 still sceptical of it (6) though most astronomers today seem to believe he actually established it). Astronomers found those dim nebulae to be immense islands of stars like our own Milky Way, called galaxies, at vast distances away, and that on its largest scale the universe was made up of countless clusters of such galaxies, stretching away as far as telescopes could see.

Starting in the 1960s Sandage (7) attempted to carry out the program laid down by Hubble i.e. to use certain galaxies, assumed to be constant ‘standard candles’, to measure the age and curvature of the Universe. Depth in the universe is very hard to gauge without assuming that such ‘standard candles’ exist. Tinsley later (1975) pointed out that Sandage’s galaxies would evolve too rapidly to remain as standards.

In 1965 Penzias and Wilson stumbled accidentally into the Cosmic Background Radiation, a microwave whisper arriving from all directions of the sky. As we interpret it now they were seeing optical radiation emitted by the gas of the universe when it was hot (3000 deg C), opaque and relatively young (300,000 years old), redshifted through the enormous factor of a thousand by subsequent cosmic expansion. This was looking into the past with a vengeance and seeing the remnants of what Hoyle dismissively called “The Big Bang”. But from now on the Expansion Theory of redshifts was accepted, usually without question, as a natural explanation for the CBR.

At the same time astrophysicists sought to explain the origin of the elements. It seemed that most would form from the fusion of pristine Hydrogen inside stars and be expelled into general circulation when those same stars exploded as Supernovae – spectacular short-lived events which can be seen out to vast distances. However the lighter elements, in particular Helium and Deuterium, would have to form much earlier during the first minutes of the Big Bang .The theory of Big Bang Nucleosynthesis set constraints on the number of baryons i.e. the amount of ordinary matter, Ω_b,in the universe (8).

Dicke meanwhile noticed a worrying paradox in the Big Bang model: antipodal parts of the cosmic horizon looked accurately the same as one another although they had never been in causal contact before (i.e. there had been insufficient time for a signal travelling at the speed of light to communicate between them). This difficulty was more or less unadmitted until Guth suggested a vague conceptual solution: “Inflation” – a slow start to expansion, followed by rapid acceleration. The necessary causal contacts could then have taken place when the universe was young but not yet flying apart too fast. If Inflation actually took place, then sufficient stretching during that period of rapid acceleration would have lowered the local curvature today so that it would *look* flat to the observer, even if it wasn’t so on a much larger scale (just as the Earth looks flat to an observer with a limited horizon) (9,10,11).

In 1978 Bosma discovered that spiral galaxies are spinning far too fast to be held together by the self gravitation of their detectable contents. There had to be far more ‘Dark Matter’ than ordinary matter. Nobody knew what it was, but if the Theory of Gravitation was right at large distances then Dark Matter was needed in spectacular amounts to hold the largest structures such as galaxies and clusters of galaxies together. Such Dark Matter might well dominate cosmology, and was indeed welcomed by most cosmologists because it might be lumpy enough to get the galaxies formed in time – another serious problem as we will see next.

The apparent uniformity of the Big Bang radiation, the CBR, led theorists to wonder how the present uneven structure of galaxies and clusters evolved out of such a smooth beginning. There must have existed certain primordial fluctuations , or elementary "seeds" (origin unknown), which somehow survived the early hot era when radiation would tear material things apart and which then grew gravitationally during the more recent cold era, to finally collapse into the galaxies we see today. A type of Dark Matter that ignored the radiation ("Cold Dark Matter" or CDM) would make an ideal survivor which could condense into lumps, thereafter dragging the much lesser amounts of ordinary matter in afterwards , matter that would eventually light up as stars.

By the 1980s the theoreticians' universe was entirely dominated by such invisible entities. Meanwhile the observers were building ingenious machines to measure what little *could* be seen, to ever greater precision. For instance optical observers could measure the spectra of thousands of faint galaxies per night and look for their motions toward the supposed foci of Dark Matter. And microwave observers launched frozen telescopes above the atmosphere to measure the spatial and spectral structure of the CBR to accuracies of parts per million. Instruments such as COBE (12), BOOMERANG (13) and WMAP (14) have apparently measured the temperature, the spatial curvature (there is none), the present age (13.4 +/- 0.3 Gigayears) and also the angular spectrum of the primordial fluctuations (seeds), as they were at a redshift of a thousand, with remarkable precision (a few per cent). Precision however does not guarantee sound interpretation.

Meanwhile Supernovae , which probe the universe at redshifts near one , had an astonishing, almost shocking story to tell (1998). The 25% dimming of such supernovae suggested that the expansion, far from being slowed by gravitation, as had naturally been expected, had instead accelerated. Moreover, this acceleration had only started in comparatively recent times (7 Gigayears ago, half way through cosmic history). The physics responsible for this recent supposed acceleration is entirely unknown but goes under the deliberately inscrutable name of 'Dark Energy'. It *may* have something to do with Einstein's Cosmological Constant Ω_Λ(15).

So the cosmological observations we have now are fairly precise, and they even fit together coherently so long as we are willing to concede that the familiar baryonic material we can observe is overwhelmed by at least 20 times as much , and perhaps 100 times as much "Dark Matter" and "Dark Energy" – which for the moment are no more than ad hoc theoretical contrivances.

The Significance of cosmology.

We now return to the preoccupations of Section Two, that is to say the difference between the number of measurements with cosmological relevance that have been made, and the number of FPs introduced to fit those same measurements. Where that difference is comfortably positive , one might regard cosmological theory as "significant" in the sense that the fit may be better, perhaps much better than one could have expected by chance. But where it is zero or negative there is no such balance of probabilities to recommend it.

Precisely which, and how many, FPs are regarded as 'Cosmological', as distinct from more widely 'Astrophysical', is to some extent a question of taste, but it does not matter so long as we treat them consistently, i.e. if included for fitting they also be included for measurement. We follow the prescription adopted by the WMAP team in Ref.(14).

We proceed by means of an historical table (Table 1) where each line introduces either new FPs (column 3) or the first (seldom the best) claimed measurement of them (column

4), with the concurrent difference in number between the two i.e. the concurrent "Significance", in column 5. This is purely a counting exercise with no real need to understand what the parameters are, or how they have been measured. Readers interested in such details can follow them up in the Notes, numbered corresponding to the lines in the Table, to be found in the on-line Supplementary Material

TABLE 1 COSMOLOGICAL PARAMETERS

	(1)	(2)	(3)	(4)	(5)
	DATE	NEW STEP	NEW FREE PARAMS	NEW MEASUREMENTS	CURRENT SIGNIFICANCE.
1	1917	Einstein's model	H_0, k_0, Ω_0	One equation between them.	-2
2	1921	Cosmological constant	Ω_Λ		-3
3	1929	Galaxy Redshifts		H_0	-2
4	1965	Cosmic Background Radiation(CBR)	η	η	-2
5	1970's	Big Bang Nucleosynthesis	Ω_b	Ω_b	-2
6	1974	Cosmochronology		$(\sim 1/H_0)$	-2
7	1978	Dark Matter	Ω_M		-3
8	1970,s	Initial Seeds	A,n_s		-5
9	1978	Gravitational Waves	r		-6
10	1981	Inflation	N		-7
11	1980's	Large Scale Structure	b,σ_8, ξ		-10
12	1990	COBE		A	-9
13	1998	Supernovae	w	Ω_Λ	-9
14	1998	Clustering		σ_8	-8
15	2000	Galaxy Infall		ξ	-7
16	2000	BOOMERANG		$n_{s,}\ \Omega_M, \Omega_0$ (k_0 inferred from equation in row 1)	-4
17	2003	WMAP	dn_s/dlogk, τ, τ_0	τ, dn_s/dlogk, b	-4

So the situation today (2006) is that the currently fashionable model of cosmology (known as "ΛCDM" to cognoscenti) has 18 free parameters (only 17 independent); 13 of these parameters are well-fitted to the data (at the 5% level and sometimes better); the gravity-wave parameter r is vague while the quadrupole parameter τ_0, Inflation N and the Dark Energy parameter w remain floating for now, leaving a net Significance of *minus* 4.To say the least this is far from healthy. Worse still, there is no sign of a systematic improvement over time. Even the three successful predictions (of apparently flat space, by Inflation; of the Light Element abundances, by nuclear theory; of the maximum ages of the oldest star-clusters, by Expansion) are overbalanced by at least half a dozen unpredicted surprises (redshifts, CBR, Dark Matter, Inflation, Dark Energy and no CBR quadrupole).

Of course there are many caveats, some pro-cosmology, some anti. On the pro- side, the counting of *independent* measurements is not trivial. Modern instruments make measurements not in a single channel but in a spectrum of channels within a given dimension (e.g. wavelength). This could increase the information returned by as much as the logarithm of the number of such channels i.e. by several. On the anti- side note that we have been counting only the FPs *explicitly admitted* within the theory. But BBC is not a single theory but 5 separate sub-theories constructed on top of one another (below). Each was selected out of an essentially infinite set of alternatives, to fit the observations as they were known at the time. By rejecting the alternatives one is, in effect, fitting several extra *implicit* FPs in each case. These extra "conceptual" FPs should arguably be added to the totals in Table 1, perhaps 2 or 3 for each sub-theory, reducing the total Significance by 10 or more. This is why such a counting exercise can never be precise.

These caveats are however arguments at the margin. A healthy theory, with a large positive Significance, could afford to ignore them. Cosmology, with its formally negative Significance, must remain for now a bloody tilting ground for its protagonists and sceptics.

So where do we stand today?

BBC is not a single theory but 5 separate theories constructed on top of one another. The ground floor is a theory, historically but not fundamentally grounded in General Relativity, to explain the redshifts – this is Expansion, which happily also accounts for the Cosmic Background Radiation. The second floor is Inflation – needed to solve the horizon and 'flatness' problems of the Big Bang. The third floor is the Dark Matter hypothesis required to explain the existence of contemporary visible structures, such as galaxies and clusters, which otherwise would never condense within the expanding fireball. The fourth floor is some kind of description for the 'seeds' from which such structure is to grow. And the fifth and topmost floor is the mysterious Dark Energy idea needed to allow for the recent acceleration of the Expansion, apparently detected in supernova observations. Thus the Dark Energy floor could crumble leaving the rest of the building intact. But if the Expansion floor collapsed then the entire edifice above it would founder. Expansion is a moderately well supported hypothesis, consistent with the CBR, with the Helium abundance and with various chronologies in our locality. However, finding more direct evidence for the universal Expansion must be of paramount importance. In the 1930's Tolman proposed such a test, really good data for which is only now becoming available (16). Tolman calculated that the surface brightness (i.e. apparent brightness per unit area) of receding galaxies should fall off in a particularly dramatic way with redshift – so dramatically in fact that those of us building the first cameras for The Hubble Space Telescope in the 1980's were told by cosmologists not to worry about distant galaxies, because we simply wouldn't see them. Imagine our surprise therefore when every deep Hubble image turned out to have hundreds of apparently distant galaxies scattered all over it [PICTURE?]. Contemporary cosmologists mutter about "Evolution" – but the omens do not necessarily look good for the Tolman test at high redshift. If Expansion were to fail then so would the entire superstructure.

In its original form, an expanding Einstein model had an attractive, economic elegance. Alas it has since run into serious difficulties which have been cured only by sticking on some ugly bandages : "Inflation" to cover horizon and flatness problems; overwhelming amounts of "Dark Matter" to provide internal structure; and "Dark Energy", whatever that might be, to explain the apparently recent acceleration. A sceptic is entitled to feel that a negative Significance, after so much time, effort and trimming, is nothing more than would expect of a folk-tale constantly re-edited to fit inconvenient new observations.

Professional cosmologists tend to put an entirely different gloss on the evidence (e.g. 17). But with a negative Significance they could well be deluding themselves. Just because an alternative hypothesis is not presently in sight, and it is not, does not mean we have to accept the only vaguely plausible one on offer. It was thus that witchcraft took hold. They may be forgetting that dimensional constraints alone can lead wildly different theories to predict closely the same quantitative results, for instance the predominant scale in the patchiness of the CBR. Anyway precision is not equivalent to reliable interpretation! And the chief 'Concordance' of BBC, which so comforts some cosmologists, namely the summation of the densities $\Omega_{\Lambda} + \Omega_{M} + \Omega_{b}$ being close to +1, the value necessary for a flat or 'Inflated' space, would indeed be impressive if only more than half a percent of the sum were made up of physically detected entities. And the apparent observation that cosmic deceleration has only recently switched to acceleration places us, from a Copernican point of view, at an awkwardly special moment of time (e.g. 18). This is the so called crime of 'fine - tuning'. And there is another more sinister pressure at work. Some, particularly in the Space agencies, worry that the general public is insufficiently interested in space-astronomy to pay for it, unless they are promised future certainties as to 'The Origin of the Cosmos'. Even if it were ethical it is dangerous to make promises based on such weak evidence.

So non-cosmologists are entitled to remain sceptical of the so called Precision version of Big Bang Cosmology even though it fits much of the data rather well, and some aspects of it, such as Expansion, are far more robust than others. Given the number of its free parameters [seventeen], so it ought. It may be healthier, as well as more exciting, to admit that we are surrounded by great mysteries which will provide challenges for generations to come. More fundamentally, as Daniel Boorstin the historian of science remarked: " The great obstacle to discovering the shape of the Earth, the continents and the oceans was not ignorance but the illusion of knowledge. Imagination drew in bold strokes, instantly serving hopes and fears, while knowledge advanced by slow increments and contradictory witnesses. " (19). If we are not appropriately sceptical about cosmology today then the current myth, if myth it is, could likewise hold up progress across all of extragalactic research for generations to come.

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NOTES on Table 1: {NB ONLY TO GO IN ON-LINE SUPPLEMENTARY MATERIAL}

1) Einstein's original model had 3 FPs: H_0 is a measure of the current rate of expansion (or correspondingly the age since the beginning); k_0 a measure of the spatial geometry , with 3 possible values, -1 for open, 0 for flat (Euclidean) and +1 for a closed finite geometry; Ω_0 is a positive parameter of order 1 which describes how dense the universe is , and therefore how its dynamics will develop under the influence of gravity. We put the Significance in col 5 at minus 2 rather than minus 3 because there is an equation relating the three FPs.
2) Ω_Λ is the notorious 'Cosmological Constant' originally introduced to enforce a static universe, as Einstein supposed it had to be. H_0, Ω_0 and Ω_Λ may vary with time. Later subscripts attached to Omega describe the densities of individual components – thus Ω_b for the density in baryons i.e. ordinary matter.
3) Hubble tried to measure H_0, the rate of expansion , using variable stars as standard candles. His answer was dramatically wrong (it implied a cosmos younger than the Earth) but at least it *was* a measurement, hence 1 has been added to col. 5. Here and hereafter it is the *first* measurement of a FP which is entered in the Table even if much better measurements follow later. Modern measurements of H_0 are probably accurate to 10 per cent or even better.
4) The initial discovery of the CBR was essentially a measurement of the current radiation temperature of the cosmos and hence of η, the cosmic photon-to-baryon-ratio, nowadays a constant. Since one measurement and 1 FP were added here the significance in col. 5 didn't change. Even so the discovery of the CBR was of great *qualitative* significance for it was the first suggestive physical evidence of a former hot, dense state.
5) Big-Bang-Nucleo-Synthesis compared nuclear theory and laboratory measurements with astrophysical observations of cosmic Helium and other light elements, to place an upper limit of less than .04 (written '< .04') on the cosmic density Ω_b of baryons alone. Today the best CBR data imply $\Omega_b = .047 +/- .006$. No Helium abundances lower than the Big Bang prediction have been reliably measured.
6) Attempts were made to estimate the ages of Globular Star Clusters, which are apparently very ancient, by comparing their stellar inhabitants with complex computations of stellar evolution. Assumptions were required : however the ages so estimated were at least of the same order as the cosmic expansion time ($1/H_0$) i.e. about 10 Giga-years. Other consistent ages (eg radioactive ones) have also been found. These ages, which are only local to our Galaxy, and 5) ,provide strong, albeit indirect support for Expansion.

7) The observational need to stabilise galaxies and clusters against their rapid internal motions necessitated the introduction of overwhelming amounts of Dark Matter, here parameterised by Ω_M (all matter), which is distinct from Ω_b (above) which refers to baryons alone. Modern values are about $\Omega_M = 0.3$ and $\Omega_b = .05$ compared to the density $\Omega_\bullet = .004$ of structures we

can actually observe because they emit starlight. From now on we are in a universe dominated by theoretical chimera. The Dark Matter hypothesis itself has increasingly severe problems. For instance it predicts far too many dwarf galaxies and giants that are too young to match the observations.

8) Without some primordial i.e. God-given fluctuations (seeds), the structures we see today would never have developed in an expanding universe. Theoreticians interested in structure-formation introduced the simplest possible spectrum of primordial fluctuations described only by an amplitude A and a spectral index n_s which relates power to physical size (i.e. the relative number of small seeds to large ones). Certain theoretical arguments suggested (no more) a natural value for n_s of +1(i.e. equal numbers of big and small seeds).
9) It was realised that a 'sea ' of very-hard-to-detect gravitational waves, characterised by a parameter r, might fill up space and affect both its geometry and dynamics.
10) Guth's Inflation hypothesis, introduced to explain Dicke's causal paradox, invokes one new FP 'N' – the number of logarithmic times the universe inflated during the supposed very early Inflation epoch. Adopting Inflation is, from a philosophical viewpoint, an act of absolute despair as it removes from us for ever any hope of measuring the real spatial curvature and thus of knowing whether space is infinite or not. And this surely was one of the driving motives for the entire cosmology enterprise.
11) The gravity of the primeval Dark Matter seeds ought to draw galaxies towards them so that contemporary large-scale *visible* structures , such as clusters, ought to be related to the underlying Dark-matter concentrations. The denser the universe (i.e. the larger Ω_M) the more dramatic the current lumpiness (σ_8) ought to appear, so attempts have been made to reverse the argument and infer Ω_M from the visible lumpiness described by σ_8, and the local velocity-streaming ξ of visible galaxies towards such lumps. Unfortunately galaxies might well have formed preferentially in denser regions in the first place , so a get-out parameter b – "the biasing parameter" – was introduced to take account of this. The best the observers could then hope to measure was some combination like $\xi = \Omega_M{}^{0.5} / b$ or $\sigma_8 = \Omega_M{}^{0.6}/b$ which are useless cosmologically without some *independent* knowledge of b. And as a consequence of this uncertainty the Significance was actually reduced by 1.
12) The COBE spacecraft reassuringly confirmed the Black Body spectrum of the CBR and made a first crude estimate of the fluctuation amplitude A, at a redshift of 1000, which was to be much refined by BOOMERANG and WMAP. No alternative explanation for its thermal spectrum, apart from Expansion, has proved satisfactory.
13) The apparent brightness of Type 1a supernovae (which ought to be standard candles if we have understood their physics aright) as a function of redshift, demanded an accelerating universe with a high Cosmological Constant $\Omega_\Lambda = 0.7$. This was dubbed "Dark Energy" (see note 2) though its physical nature is as mysterious as its measured result was surprising. This implied a relation between cosmic pressure p and cosmic density ρ of the form $p=w\rho$ where w is negative but unknown. The measurement of Ω_Λ, but the introduction of w, leaves the Significance unchanged.
14) The amplitude of galaxy clustering (σ_8) was estimated from optical surveys.

15) Likewise the perturbation in galaxy velocities ξ due to the gravitational fields of large-scale structures were estimated from huge numbers of faint galaxy redshifts.

16) BOOMERANG , the Antarctic Balloon telescope, brought back the first accurate images of patchiness in the CBR, at a level of one part in a million. The angular scale of the most prominent irregularities yielded a first measure of the geometry and thus of Ω_0. This, together with H_0, and the equation alluded to in 1) revealed what *looks* to be a spatially flat universe (i.e. $k_0 \approx 0$ today) which has been regarded in some ,but not all quarters, as support for Inflation.It also found a primordial fluctuation spectrum ($n_s \approx 1$) that is roughly "scale-free" i.e. as simple as possible. The Significance increased by no less than 3.

17) WMAP, the analogous satellite experiment, is providing even better geometrical information which confirms BOOMERANG but goes further. Its polarisation information yields τ, essentially the age of the universe when its cool expanding gas was re-heated by ultra-violet radiation from the discrete bodies, such as stars and galaxies, that had recently formed within it. The WMAP data are better fitted by arbitrarily altering the model for seeds so that their spectral index curves (thus introducing the new FP $dn_s/d\log k$), but this FP is estimated from the data. However on very large scales i.e. half way across the sky, the data do NOT fit the model. If the sky *were* too lumpy on that scale one might ascribe that misfit to chance local conditions ('variance'). However the misfit is in the opposite sense – the microwave sky is too flat – there is for instance no quadrupole component. The WMAP team suggest that an arbitrary (for now) misfitting parameter τ_0 be introduced to allow for this. Little b is inferred to be = +1 (no biasing) from the measurement of Ω_M. Altogether the Significance is increased by 1.