A NEW EXPLANATION FOR THE COSMIC MICROWAVE BACKGROUND RADIATION TEMPERATURE

Professor Robert Temple
The History of Chinese Science and Culture Foundation
Conway Hall
25 Red Lion Square
London WC1R 4RL, England
robert.temple@china-infonet.com

Accepted for publication June 21, 2017.

ABSTRACT

Reasons are given for regarding the temperature 2.73K of the cosmic microwave background radiation as a fundamental and permanent aspect of the Universe, based upon natural constants, rather than as being a remnant of the higher temperatures of a Big Bang cosmic primaeval creation explosion. It is proposed that 2.73K is itself a natural constant, as is 273K, being the temperature of the triple point of water. The uniqueness of the Kelvin Scale is emphasized, in enabling us to see the connection between the two constants, and to see several other manifestations of them in Nature as well. It is proposed that the cosmic background radiation at 2.73K, as the perfect black body state, and in view of its isotropic nature, is an important phase transition point for matter throughout the Universe, and can be understood in connection with the strong nuclear force.

KEY WORDS: Cosmic microwave background radiation, Big Bang, Kelvin Scale, triple point of water, Helium 3, Helium 4, pions, meson clouds, strong force

A NEW EXPLANATION FOR THE COSMIC BACKGROUND RADIATION TEMPERATURE

A great deal of discussion has taken place for several decades now concerning the temperature of 2.73K, which is often referred to as the number describing the temperature of 'the background radiation of the Universe'. Because this temperature is essentially isotropic, it has become conventional to describe it as left over from 'the Big Bang' at the 'creation of the Universe'. No one seems ever to have come up with any other convincing explanation for the highly precise number attached to this background radiation. Whether one agrees with the Big Bang Theory or not, one must recognise that because of the isotropism of these readings, and the fact that it appears therefore to be a universal phenomenon essentially spread evenly (allowing for the odd anomalous region) across the whole known Universe, it is reasonable to have as one possible theory that it could be some kind of cosmological primaeval leftover from a much higher temperature at the time of the initial 'creation' of the Universe. The 2.73K, most astrophysicists think, must be a kind of faint ember of what was once a raging 'fire of creation' of vastly greater temperatures. In other words, it is thus assumed to be a pathetic cosmic remnant, a feeble trace of what were once the forces of the primaeval creation explosion. The cosmic microwave background radiation (CMB) was discovered in 1964/5 by Arno Alan Penzias and Robert Woodrow Wilson of the Bell Labs, for which they got the Nobel Prize in 1978. This discovery was very rapidly used by Big Bang theorists in the 1960s to 'win' their dispute with theorists of what was then called the Steady State Theory.

Those who oppose the Big Bang Theory have over the decades produced many impressive arguments for their cause, but they always come up against the apparently intractable problem of the cosmic background radiation. For them, the number 2.73K must sometimes seem to be the number from hell. How can they possibly get rid of this number so that their other arguments can gain listeners? As long as the number 2.73K is there blocking the way, it is easy for scientists of other persuasions to justify ignoring their other points of argument. After all, if the cosmic background radiation is an impermeable barrier to dissent, why listen to any?

But what if the number 2.73K signifies something entirely different from what everyone has so far imagined? What if it has nothing whatever to do with an early creation explosion, but has everything to do with entirely other aspects of the structure of the Universe? What if it is absolutely necessary, fundamental, and has in fact never changed, and never can change?

We need to look at this problem in a completely new way. I believe I can offer an explanation which settles the fraught disputes over the number 2.73K by showing that it means something else. And for this explanation to be true, *the number needs to be isotropic throughout the Universe*.

This turns the argument for the Big Bang Theory on its head. Big Bang theorists insist (as to them it has seemed so obvious) that it is the isotropic nature of 2.73K which means it must stem from the creation of the Universe. How else could it become isotropic? The reasoning is that if it came from a central point, that is how it got everywhere, and if not, how could it arise everywhere spontaneously and be the same in every direction, without any point of origin? The logic involved here is simple and direct, but perhaps too simple and direct. However, if there is another explanation for the isotropism, then there is no need to insist on the Big Bang Theory as its only possible explanation. Cosmologists can then feel free to argue about their rival cosmologies on all the other points which concern them, which is certainly not my purpose here. This discussion is intended to be neutral in such disputes.

The first thing which is necessary is to consider where the number 2.73K came from. As all physicists know, it came from the Kelvin Scale. It is crucial to remind ourselves that the Kelvin Scale is rooted in natural phenomena and does not rely upon any arbitrary number or numbers, substance or substances. All of us, whether we recognise the fact or not, are in a debt of gratitude to Lord Kelvin (1824-1907) for constructing a temperature scale which stands apart from human imaginings. It is worthwhile to remind ourselves at this point of the basis on which this scale was established. Lord Kelvin, when he was still called Sir William Thomson, published a famous article in 1848 entitled 'On an Absolute Thermometric Scale'.[1] In this early article, calling for the construction of a new and 'absolute' temperature scale, which he then constructed, he makes the following comments:

'… the scale which is at present employed for estimating temperature is that of the air-thermometer … The principle according to which the scale of the air-thermometer is graduated is simply that equal absolute expansions of the mass of air or gas in the instrument, under a constant pressure, shall indicate equal differences of the numbers on the scale; the length of a "degree" being determined by allowing a given number for the interval between the freezing- and the boiling-points. … Although we have thus a strict principle for constructing a *definite* system for the estimation of temperature, yet as reference is essentially made to a specific body as the standard thermometric substance, we cannot consider that we have arrived at an *absolute* scale … In the present state of physical science, a question of extreme interest arises: *Is there any principle on which an absolute thermometric scale can be founded?* It appears to me that [Nicolas] Carnot's theory of the motive power of heat enables us to give an affirmative answer.

'The relation between motive power and heat, as established by Carnot, is such that *quantities of heat*, and *intervals of temperature*, are involved as the sole elements in the expression for the amount of mechanical effect to be obtained through the agency of heat; and since we have, independently, a definite system for the measurement of quantities of heat, we are thus furnished with a measure for intervals according to which absolute differences of temperature may be estimated. … The amount of mechanical effect to be obtained by the transmission of a given quantity of heat, through the medium of any kind of engine in which the economy is perfect, will depend, as Carnot demonstrates, not

on the specific nature of the substance employed as the medium of transmission of the heat in the engine, but solely on the interval between the temperature of the two bodies between which the heat is transferred. …

'The characteristic property of the scale which I now propose is, that all degrees have the same value; that is, that a unit of heat descending from a body *A* at the temperature T^0 of this scale to a body *B* at the temperature $(T\text{-}1)^o$. This may justly be termed an absolute scale, since its characteristic is quite independent of the physical properties of any specific substance.'

Kelvin then adds in a footnote his comments on what we now call Absolute Zero, but which he calls 'infinite cold':

'… infinite cold must correspond to a finite number of degrees of the air-thermometer below zero; since if we push the strict principle of graduation, stated above, sufficiently far, we should arrive at a point corresponding to the volume of air being reduced to nothing, which would be marked as -273^o of the scale … and therefore -273^0 of the air thermometer is a point which cannot be reached at any finite temperature, however low.'

In this paper, Kelvin makes no mention of the triple point of water, which was later to become associated with the Kelvin Scale. It was Kelvin's brother James Thomson who, in 1873, demonstrated and introduced the name for the triple point of water in a paper where he stated '… the three curves would meet or cross each other in one point, which I have called the *triple point*.'[2] (The three curves were of course those of the solid phase, the liquid phase, and the gaseous phase.)

James Thomson in his paper mentions that he conferred with his brother in October 1872 about these matters and that he incorporated some findings of his brother in his own paper, namely his brother's formula for expressing 'the second law of thermodynamics for a body of uniform temperature throughout, exposed to pressure equal in all directions'. [3] This is an important point, because he was able to speak in terms of pressure rather than in terms of volume, thus taking considerations of volume away from the discussion and replacing them by considerations of pressure. For further details, one should consult the entirety of James Thomson's paper, as it would be unfair to present a summary of such a meticulously crafted discussion.

At this point I wish to bring forward the first important point. We note that the same numerical coefficient occurs twice in relation to the fundamental bases of the Kelvin Scale, namely the number 273: it occurs once as 2.73 and again as 273. It cannot have escaped the notice of many scientists over the years that, as the value of zero degrees Centigrade, i.e. the triple point of water, is equal to 273K, and the temperature of the cosmic microwave background radiation is $(273)^{-2}$K, they may have wondered whether it could possibly be a coincidence that the identical number, differing only by two powers of ten, could thus occur twice with regard to fundamental cosmic temperatures – in other words, is it 'just one of those things that happens with numbers'. Or could there possibly be some deeper significance to this?

The first observation to make is that when we take the two together we get a fixed ratio. That ratio is *one percent*. Already our view of the temperature 2.73K takes on a different aspect. It is no longer 'just a number', it is now one half of a basic cosmic ratio. We have two fundamental cosmic temperature points which can be expressed by the same numerical coefficient. It stretches credulity too far to maintain that this could possibly be a coincidence. We can now state that:

The temperature of the cosmic background radiation is one percent of the temperature of the triple point of water.

So where does the Big Bang fit into this? It does not.

But in order to substantiate this point, it is necessary to go on to the next, which is somewhat more complex.

In order to explain the alternative source of 2.73K, it is necessary for me to refer to my rather lengthy paper which appeared in this journal last year.[4] In that paper, I originated a new symbol, *ř*, in homage to the Swedish scientist Johannes Rydberg (1854-1919), to stand for the number 136, which appears in so many manifestations in relation to various natural constants, not least the Rydberg Unit of Energy. (The Fine Structure Constant is *ř* + 1, for instance. Lest anyone be doubtful of the importance of the addition of unity to a key number in physics, I have called attention in my earlier paper to what is generally called 'the *n* plus one formalism' in quantum theory, and its general implications are discussed and examples given.) I was able to come up with a very simple formula for the rest mass of the proton using this symbol. Many other formulae were presented on a similar basis, and simple connections were demonstrated between several natural constants which had never previously been seen to be linked, such as the Rydberg Unit of Energy and the Planck Constant. I cannot reprise the 95 pages of that earlier paper here, but the formulae were justified by reference to many findings by numerous famous figures both in contemporary physics and in the history of physics. And indeed the numbers do not lie, so the numerical evidence stands, whatever theory one might adopt to try to explain them. My paper did not advocate any theories, with the minor exception of a new explanation for the strong nuclear force. It was therefore essentially a phenomenological rather than a theoretical paper. The same is true here, where my suggestion of a new explanation for the 'cosmic microwave background radiation temperature' is presented not as a grand cosmological theory but as a mere phenomenological observation based upon numbers, together with a brief consideration of the wider significance of those numbers. What one does with that in terms of grand theories is for others who are more directly concerned with such things to decide.

In my previous paper I adopted one unfamiliar technique of moving decimal points as a simple way of speaking of changes of powers of ten in relation to the changing manifestations of certain natural constants. I also from time to time detached decimal increments and treated them separately, calling them 'mantissas' in homage to the strange mathematical genius John Napier, whose mathematical innovations leading to the invention of logarithms have never

ceased to be considered a marvel of ingenuity by the generations who succeeded him. Some of Napier's mental leaps still puzzle us today. So I have dared to copy one of his leaps, and it has appeared to yield results.

Let us now examine this number 273, treating it as a numerical coefficient which can operate at different powers of ten, and see where it occurs in science. The first thing I would like to point out, and which I discussed in my earlier paper, is that the ratio of the joint rest masses of the pion$^+$ and the pion$^-$ to the rest mass of the electron is 273. The simple arithmetical formula for the number 273 is this: ŝ = 2ŕ +1, and that is thus also the formula for the value of the ratio which I just mentioned. (The mean rest mass of the two pions is 137, or ř + 1.) The reason for stating such simple formulae is to compare them, which helps us to see what is going on with the numbers which underlie the phenomena.

The number 273 comes up again in one of the three conventional expressions of the Avogadro Number, where it is stated to be 2.73159734 x 10^{26}. This is clearly related to the Kelvin Scale, but is worth mentioning as a reminder to readers.

I now turn to the number 273's relationship to the number 136 which I have designated by the symbol ř, for reasons explained at very great length in my previous paper, so that I cannot repeat all of that here. In that earlier paper I demonstrated that the number 273 can be derived from ř in 'two entirely different ways: on an additive basis and on a multiplicative basis (i.e., from a square). … Is it significant that 273 can be derived in the two separate ways from ř, based on the one hand on an addition and on the other hand by a multiplication …?'[5]

I need now to refer briefly to what I believe to be the fundamental origin of the number 273, but in order to do that I must mention something usually known only to advanced musicologists, namely what is called the Comma of Pythagoras, the decimal value of which is 1.0136. This number was known to proto-scientists of ancient Greece since at least the time of Pythagoras (circa 570 BC – circa 495 BC). It was discovered empirically by people such as the Pythagoreans who were studying harmonic theory in music by measuring musical instrument (especially monochord) string lengths and comparing them. (They had to use string lengths to get their numbers because they could not measure frequencies as we can; string lengths give the inverse forms of frequency numbers, by the way, so the Greeks were still getting the right numbers but merely in inverse form.) Before modern times, when the number was converted to decimal form as 1.0136, the number was expressed as a fraction, but as I explained in my earlier paper, one very ancient surviving Greek treatise gives a fraction value for it which converts to a decimal which is accurate to an astonishing nine decimal places.[6] The Comma of Pythagoras expresses the arithmetical incommensurability of the rising or falling musical scales based on the one hand upon musical fifths and on the other hand by musical octaves. Most people who are not musical have no idea that these two are incommensurable. The value of the incommensurability is precise and universal and is a great puzzle of the Universe. Physicists rarely know of it, as it appears to be outside their discipline. But alas, it is not outside their discipline at all, as I have demonstrated in my earlier paper at some length.

As far as musical harmony is concerned, equal temperament was invented to compensate for this awkward incommensurability, so that composers could modulate between keys. But they do so at a cost. A little bit is shaved off each tone, so that each is slightly flat. (Someone with perfect pitch can detect this directly by ear without taking any measurements.) I have published an account of equal temperament's invention in China at the end of the Ming Dynasty, and how it spread to Europe, where it became advocated by Johannes Sebastian Bach.[7] As a result, modern symphonies became possible. But I cannot here enter into any further discussion of musical theory, which has been done in my earlier paper and does not need to be repeated.

What I was able to discover about the Comma of Pythagoras is that, if taken as a decimal (which in ancient times did not occur), one can find the significance of the numerical coefficient occurring in its decimal increment, by detaching it and treating it as a 'mantissa'. This is where the Napierian 'leap' comes in. As soon as one does that, one can begin to see all the occurrences of this number throughout physics, at various powers of ten, and sometimes qualified by the '*n* plus one formalism' of quantum theory (see below). This in turn leads to detecting connections between numerous natural constants which had previously appeared to be unrelated to one another.

The square of the Comma of Pythagoras is 1.0273. If one detaches the decimal increment as a 'mantissa', one thus has the numerical coefficient 273 at a lower power of ten, i.e. 273^{-2}. If one were to adopt a symbol for the number 273, one could use *š*. That shows a continuity with *ř* by using the same Czech consonantal marking, and it is the next consonant in the alphabet.

I now want to turn to the appearance of $\check{s}^{-2}$K as the measure of the temperature of the cosmic background radiation.

As we have seen that *ŝ* can be derived in two different ways from ř, is there any other occurrence of either *ŝ* or *ř* relating to measures in Kelvin which shows up at a fundamental level in chemistry or physics? The answer is yes, and in fact it relates back directly to a transition temperature for water. If we look at $Helium^4$ and $Helium^3$, we see that the first liquefies at 4.2216K and the latter liquefies at 3.2K. The mean between the two is 3.7K, and that value is 0.0136^{th} of the triple point of water, 273K. Let us represent 3.7K by *Ĥ*. Then:

$$\hat{H} = \check{r}^{-4} + 1 \qquad (1)$$

But since $2\check{r} + 1 = \hat{s}$, by substitution we may express *Ĥ* in terms of *ŝ* as:

$$\hat{H} = (\hat{s}-1 / 2)^{-4} + 1 \qquad (2)$$

In both expressions we find in operation the '*n* plus one formalism' of quantum theory, which I have discussed in my previous paper, citing in particular the brilliant discussions of it by Albert Rose and by Léon Brillouin (who called it the (1 + *p*) formalism). Brillouin made it clear that the addition of unity should be seen as an added *capacity* rather than as an added quantity or entity.

This finding extends yet further the occurrence of $\hat{s}$ within the realms of temperature physics. So, associated with $\check{s}$, we now have:

(a) Absolute Zero; (b) the cosmic microwave background radiation; (c) the liquification of Helium 3; (d) the liquification of Helium 4; (5) the triple point of water. In addition, of course, we recognise that the triple point of water effectively serves as the actual basis for the Kelvin Scale, as each degree (or 'kelvin') of that scale is officially defined as being 1/273th of the thermodynamic temperature of the triple point of water. (Please note that for the sake of simplicity throughout this paper I have disregarded the decimal increments which can occur beyond 273, whether one regards them as 15 or 16, as there seems to be some dispute about which is accurate.)

I propose that if we find that we need a symbol for the cosmic background radiation temperature value of 2.73K, we might use $\hat{c}$. In that case, $\hat{c} = \check{s}^{-2}$.

There is another occurrence of $\check{r}$ in relation to water: the density of liquid mercury is 13.6 times the density of water; in other words, it is $\check{r}^{-1}$. Or one can express that by saying that the density of liquid mercury is $(\hat{s} – 1 / 2)^{-1}$.

The boiling point of aluminium is 2740K, or $((\hat{s} + 1) \times 10)$K. It is worth noting also that the boiling point of magnesium is 1380K, or $((\check{r} +2) \times 10)$K. The melting point of copper is 1356.6K, which rounded off is $(\check{r} \times 10)$K.

Considering the importance of the triple point of water to the Kelvin Scale, it is worth noting that the triple point of hydrogen is 13.8033K, which is $(\check{r} + 2)^{-1}$K. (In my earlier paper the progression 136, 137, 138 was shown to be important with natural constants, and the reasons were explained, which cannot be repeated here.)

Another curiosity which I might mention is that the boiling point of bismuth is 1837K, the numerical coefficient of which is equal to that of the rest mass of the proton plus one. (For the possible implications of this one would have to read my previous paper, which derives a formula for the ratio of the rest mass of the proton to that of the electron based upon $\check{r}$. See also the comments there about the neutron.)

In my previous paper I concentrated upon showing formulae for numerous phenomena of physics and astronomy and also connections between various natural constants in terms of $\check{r}$. In each case, a substitution in terms of $\hat{s}$ may be made very simply, as I have just shown twice above.

Let us now take stock of what these disparate facts and numerical occurrences may possibly mean, and whether there be anything that brings them together, so that we can see whether $\check{s}$ stands for any kind of general principle.

Helping us are those key mesons known as the plus pion and the minus pion. The mean rest mass of these two pions is 137, or $\check{r}$ + 1, and the ratio of the joint rest masses of the two pions to the electron is $\hat{s}$. What is it about mesons that may

give us the key? They are essentially connectors and binders, or one might say mediators. And one might also say that they are *facilitators of capacities*, bearing in mind the statement by Brillouin referred to a moment ago.

As we see that the temperature measured by the unique Kelvin Scale, which eliminates all arbitrary measure, of the cosmic microwave background radiation is $\check{s}^{-2}$ on that scale, and the temperature of absolute zero on the Centigrade scale, i.e. the triple point of water, is $\check{s}$ on that scale, then we can be justified in regarding the value $\hat{s}$ as worthy of being considered as a natural constant. As it is a natural constant, it cannot or should not vary. This suggests that it should be ruled out as being an arbitrary remnant temperature of an originally much higher temperature. Whether the Universe was created by an immensely high temperature in a Big Bang or not, this should have nothing to do with $\hat{s}$. And hence we should remove this temperature as indicating a Big Bang origin of the Universe. It should instead be regarded as neutral in that discourse, and indicative of something wholly other.

If we can free ourselves from the preconception that the cosmic microwave background radiation is a remnant of a creation fireball, then we can begin to think about its true significance. It is clearly a universal marker and has a status analogous to such other markers as Absolute Zero and Zero degrees Centigrade. There are many fundamental 'markers' in physics. There is for instance the velocity of light. Another marker is the dimension of 10^{-13}, where quantum mechanics takes over. Another is the Curie Point, and so on. In fact, all phase transition points are markers, in the broader sense.

Since the cosmic microwave background radiation is known to be 'the most perfect black-body radiation ever observed in Nature', to quote one famous description of it, perhaps we should face the consequences of that and regard 2.73K as the point at which atomic matter in cosmic thermal equilibrium becomes capable of yielding to change by 'melting', as it were, so that it can rise above being a perfect black body, and those intermediaries known as pions, which form meson clouds around the nucleons, can transact their business by being emitted and absorbed by the nucleons. And that business consists of carrying the strong nuclear force (in the manner proposed in my earlier paper, by an amplification process made possible by helicity), according to the ideas of Hideki Yukawa as formulated in 1934, so that forces can act between nucleons by what is called 'the exchange potential'. Protons can then change into neutrons and neutrons can change into protons. The pions are force-bearing particles, and the joint rest masses of the plus and minus pions has a ratio with the electron bearing the same numerical coefficient as the temperature of the cosmic background radiation. In other words, 273 manifests at 2.73K. In this sense we are faced with a universal natural constant. It is only the preconception that 2.73K is a leftover of a cosmic fireball of creation that has blinded us to this. We might call this phase transition point of 2.73K something like 'the nucleon force release point', or 'nucleon melting', with its concomitant release and absorption of pions. Experimentalists might find some way of testing this hypothesis directly or at least of exploring the implications of this in some way as yet untried.

11

It seems that the only previous persons who have suggested that 2.73K might have a fundamental interpretation were Hoyle, Wickramasinghe, and Reddish, in a paper in *Nature* published in 1968.[8] Wickramasinghe and Reddish had previously published a discussion of the condensation of solid hydrogen on graphite grains in interstellar clouds. With Hoyle, they then extended their discussion and called attention to the vaporization of solid hydrogen at approximately 3K. They specifically called attention to 'The similarity of the microwave background temperature to the temperature … of the heat of vaporisation of solid hydrogen.' In other words, they were really referring to 2.73K and pointing out the numerical coincidence. This early insight fits very neatly into the framework outlined in this paper, since those authors called attention to a phase transition point for the simplest of nucleons at precisely where I have suggested above that that temperature could be described as 'the nucleon force release point' or 'nucleon melting'. I was unaware of the 1968 paper when I wrote the rest of this paper, but the 1968 paper was brought to my notice by a peer reviewer prior to publication, so that I have been able to incorporate mention of it here, and for further understanding of that seminal paper, the authors' own words should be consulted. But it is the most uncanny thing that the vaporization of solid hydrogen should also be related to 2.73K, as that is precisely a form of 'nucleon force release', exactly as I 'predicted' above. I say 'predicted' in quotes because unknown to me, this 'prediction' had in a sense been partially verified in advance, 49 years prior to my making it, but was apparently never mentioned by anyone again. I must confess that I was not reading *Nature* in 1968, and unfortunately articles that far back tend to be forgotten. I am extremely glad that I can cite this history, or should I say this hidden pedigree, of the type of concepts expressed in this article, and show that some of the finest astrophysicists of our time had long before anticipated what I have tried to suggest here. I only wish that more people had taken note of what they said back then, which seems to have fallen on deaf ears at the time.

Cosmologists have become habituated for decades to regarding 2.73K as a transient temperature which is merely a pathetic leftover from the grand old days of a proper cosmic fireball, in other words, a kind of cosmic whimper. I prefer to regard 2.73K as a roar rather than as a whimper. It is the roar that says: this is cosmic thermal equilibrium from which you can now escape. And as Prigogine might say, we want to get as far from that as possible.

---

[1] Sir William Thomson (later Lord Kelvin), 'On an Absolute Thermometric Scale Founded on Carnot's Theory of the Motive Power of Heat and Calculated from Regnault's Observations', in *Philosophical Magazine*, October, 1848; reprinted in the author's *Mathematical and Physical Papers*, Cambridge University Press, Volume One, 1882, pp. 100-106.

[2] James Thomson, 'A Quantitative Investigation of Certain Relations between the Gaseous, the Liquid, and the Solid States of Water-substance', in *Proceedings of the Royal Society*, Volume 22, 1 January 1873, pp. 27-36.

[3] *Ibid.*, p. 30.

[4] Robert Temple, 'Is Particle Mass a Function of Degrees of Freedom?', *Journal of Cosmology*, Vol. 26, No. 3, 2016, pp. 13995-14090.

[5] *Ibid.*, p. 84.

[6] The work is the *Katatomē Kanonos* (*Division of the Canon*), edited, translated and published for the first time in 1991. See footnote 8 of my previous paper, *op. cit.*

[7] Robert Temple, *The Genius of China: 3000 Years of Science, Discovery & Invention*, André Deutsch, London, 2013, pp. 234-9.

[8] Sir Fred Hoyle, Chandra Wickramasinghe, and Vincent Reddish, 'Solid Hydrogen and the Microwave Background', *Nature*, Volume 218, 22 June 1968, pp. 1124-1126.