# A PROPOSED SOLUTION TO THE DARK MATTER MYSTERY

BY ARDESHIR MEHTA

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## INTRODUCTION

For several decades it has been believed that the mass of the universe is much greater than can be accounted for by the mass of the luminous matter in it.

As an example, the force of gravity produced by each galaxy – which in turn is affected by the distribution of mass in the galaxy – seems to be inadequate to counter the centrifugal force generated by the rotational motion of the stars in the galaxy. As things stand, given their speed, the stars in a rotating galaxy all ought to fly off at a tangent from the galaxy, which does not seem to happening. So if the stars are held in their orbits by gravity alone, there must be some mass drawing the stars in towards the centre of the galaxy.

To give another example, the gravitational pull generated by the mass of all the stars in all the observed galaxies is not sufficient to account for the clustering and super-clustering of galaxies in the manner they appear to be clustered in the visible universe. Without some "missing mass" pulling them together, there does not seem to be any explanation as to why they are all so close to each other.

Consequently, it has been estimated that at least 50 per cent, and maybe as much as 90 per cent – some scientists say, 95 or even 99 per cent – of the mass of the universe is in the form of "dark matter": namely, matter which does not give off radiation, at least not in quantities appreciable enough to be detected by our present telescopes, radio-telescopes and other such instruments.

There has been considerable speculation as to what exactly this "dark matter" consists of. Various exotic hypotheses have been proposed: that it comprises "cosmions", or "WIMPs" (Weakly Interactive Massive Particles), or black holes, or cosmic strings, or neutrinos possessing appreciable mass, or "brown dwarf" stars, or even more exotic material. Nevertheless, it has not been determined exactly what this "dark matter" is, nor how much of it there is in the universe. It remains a mystery to this day.

(Of course, the above assumes that gravity alone is responsible for countering the centrifugal force of rotation of a galaxy, and for the clustering and super-clustering of galaxies themselves: and this is the assumption made by almost all cosmologists today. However, even if this is not the case – as is asserted by those who postulate that electromagnetic forces are involved in these processes – most of the arguments elucidated below still apply.)

This essay proposes at least a partial solution to the question of whether "dark matter" exists at all, and if so, in what form. A conjecture is also made as to how much of it exists. In addition, it will be shown that it would be impossible, at current levels of science and technology, and given our present knowledge of the laws of nature, to observationally determine the exact amount of "dark matter" in the known universe.

## ASSUMPTIONS MADE AT PRESENT

Some cosmologists, such as those who believe in the plasma theories of Nobel Prize winner Hannes Alfvén, claim that there is no "dark matter". This can't be true, as should be obvious, even to those who espouse such theories. According to them, stars and galaxies are formed, not as a result of the action of gravity alone, but as a result of the actions of the electromagnetic force – which is $10^{42}$ times more powerful than gravity – acting on vast quantities of plasma, or charged particles, which are presumed to pervade space. If these theories are true, then of course, the *plasma itself* must be at least part of the "dark matter." So even in a "plasma universe" there *must* be some "dark matter". But as we shall see below, there must be much more.

In this essay, to begin with, it will be logically demonstrated that no matter which model of the universe is true, "dark matter" *must* exist in the universe. To this end, we will begin by showing that even to *expect* that the mass of the universe ought be equal to the mass of the luminous matter in it – or even approximately so – is somewhat short sighted, and indeed illogical. This has happened, however, because of erroneous assumptions tacitly made by scientists when attempting to determine the mass of the universe.

For instance, most scientists make the assumption that the mass of a star is equal to the mass of the material contained *inside* the star: i.e., within the spheroidal plane which forms the visible surface of the star. A bit of simple logic will show this assumption to be quite erroneous, even though understandably so.

## A Thought Experiment (After the Manner of Einstein)

To demonstrate this error, let us conduct a "thought experiment", the way Einstein used to do. Let us imagine a couple of candles, each having an unburnt mass of 10 grams. As they burn, they lose mass ... don't they?

Yes, in a sense, they do; but in another, more all-inclusive or universal sense, they do not.

To illustrate this more universal sense, let us think of the candles in what is called a "strictly determined closed system". Such a closed system can be, for instance, a container having a total mass of *exactly* 10 kilograms. (This would be its mass inclusive of everything in the container: the air, the two candles, the candlesticks on which the candles are mounted, and any other material that it may be made of or that may be inside it: such as dust, paint, etc.). Let the container be made so well that everything inside it is perfectly insulated from everything outside it. Now burn the candles. As they burn, *the mass of the container does not change one single jot, does it?* It remains exactly 10 kilograms: not a milligram more or less, even when the candles are completely burnt out.

Now let us conduct the same experiment using a couple of stars instead of candles. Let us imagine two stars in a strictly determined closed system: say inside a perfectly insulated container whose total mass (inclusive of the stars) is *exactly* $10^X$ kg. (For this argument, we shall say that $10^X$ is a precisely determined finite number, sufficiently large however to accommodate the two stars, with enough space around them to dissipate their light till it is too faint to make appreciable heat). Now let the stars burn. As they burn, does the total mass of the container decrease? No, of course not. Even when the stars are completely burned out, the total mass of the container will remain *exactly* $10^X$ kg: not a milligram more or less.

## Application of the Above Thought Experiment to Reality

Now some people will no doubt say, this is all very well, but let's get real: where is anyone going to find a container that large? Well, it so happens that an even larger container actually does exist. It's called The Universe, and it satisfies all the requirements mentioned above. It is a perfectly closed system; it has a total mass of exactly $10^X$ kg (even though we don't know precisely what X is!); it completely insulates everything inside it from everything outside it (even if there happens to be anything outside it!); and it can hold, not just a couple of stars, but all the stars there are, or for that matter ever were.

As the stars in the universe burn, does the total mass of the universe decrease? No, of course not. The mass of the stars simply gets redistributed. A good deal of it escapes from each star at the speed of light in the form of photons; some of it escapes in the form of neutrinos; some of it escapes as stellar wind; some of it escapes as other kinds of emanations; and whatever doesn't escape gets left behind. Even after a star is completely burnt out, the *total mass* of all the products of its burning remains constant.

So it follows logically that after a star is completely burnt out, *most* – in fact, in the majority of cases, almost *all* – of the products of its combustion are in the form of "dark matter", unless a considerable portion of that matter is used later to make up other stars. However, as we shall show, this cannot be the case for most stars.

## WHAT DOES MOST OF THE "DARK MATTER" CONSIST OF?

In the case of most stars, obviously, a great deal of this "dark matter" will be in the form of light, or photons. (We shall use these words in the broadest sense, to denote all wavelengths of electromagnetic radiation). Now it may sound somewhat strange to think of light as being "dark", or invisible, considering that light brightens all things, and is the only thing that *is* visible: it's actually everything *else* that's dark or invisible. But let's think about it for a minute: in order to be visible, the light given off by a star (or for that matter anything else) must *enter our eyes,* or at least our telescopes or other similar instruments. Obviously only a minuscule portion of the total light given off by a star is going to end up in our eyes or in our instruments. Light (i.e., photons) travelling at right angles to our line of sight – or for that matter in any direction *other* than our line of sight – must be invisible, and, therefore, "dark".

The vast majority of starlight is moving in outer space, pointed in every direction other than our line of sight; and so obviously it cannot be seen. It cannot even be illuminated: one can't light up light itself! Its presence can be inferred, but it is, to all intents and purposes, "dark".

So all photons, even those in the "visible" spectrum, are invisible and therefore "dark", unless they enter our eyes or our instruments.

But the universe must be absolutely chock full of photons! Stars have been shining for millions – even for billions – of years. All the photons they have ever emanated must all *still be there* somewhere in the universe! (They can't have gone anywhere else, now can they?)

## THE MASS OF LIGHT

And although light, being energy, may not be "matter" in the narrow, "classical" or pre-Einsteinian sense, it does have mass, as predicted by Relativity and as confirmed by many observations, and even by simple logical thought.

For instance, if light – or photons – had no mass, black holes wouldn't be black, now would they? Light would simply ... float away from a black hole: it wouldn't even need escape velocity to leave a black hole's surface. It's only *because* light has mass that it can be trapped by the black hole's immense gravitational force.

Even if black holes don't really exist – as some physicists argue – we can't forget Einstein's celebrated equation $E=mc^2$: or in other words, $m=E/c^2$. It simply means that the mass of any particular amount of light – which, after all, is pure energy – is equal to that energy divided by the speed of light squared.

Actually, one doesn't even have to be an Einstein to show that light must have mass: it follows by simple logic from our "thought experiment" conducted earlier. If light had no mass, the stars burning inside our hypothetical container would cause the container as a whole to lose mass. Such a thing would imply that one can affect objects far, far away from within a perfectly insulated container, simply by manipulating things *inside* the container. (This follows because the changes in the total mass of the container would change its gravitational field, which is the one thing nobody has figured out a way of insulating against; and changes in its gravitational field would affect everything *outside* the container, no matter how far away.) So, for instance, one could, theoretically, switch a light bulb on and off in one's basement, and by doing so jiggle the orbits of Mars and Venus. This is so patently ridiculous a conclusion that no self-respecting scientist is likely to sanction it, though it may well make a fine plot for a science *fiction* story.

Actually the notion that light has mass is also required by "Big Bang" models of the universe. (For the present we won't get into a debate whether these models accurately reflect reality or not, or whether the universe had some other origin than that implied by "Big Bang" theories. There seems to be a controversy regarding this question.) Now these models all demand that in the very first stages of the "Big Bang", the universe was dominated by radiation (i.e., light). It was only after a period of time – some models require this period to be a million years or so – when the initial "fireball" had cooled down to a temperature that allowed ordinary matter to exist in a stable form, that the universe ceased to be mostly light, and that matter appeared on any significant scale.

However, no "Big Bang" model claims that for its first million years (or whatever the radiation-dominated period is supposed to have been) the universe had next to no mass, and that it increased in mass after that time. That would be like claiming that huge amounts of something – namely gravitational force – could be produced out of nothing. This sort of claim is hardly possible to sustain by any observation yet made.

So if any of the "Big Bang" models actually reflects reality – about which, however, there is quite a bit of doubt, at least in the minds of a few scientists, since (among other difficulties) "Big Bang" theories imply that *everything* was produced out of nothing – then the universe must have had the same mass when it was (theoretically) dominated by light, as it does now when it's (apparently) dominated by matter. Therefore "Big Bang" theories absolutely demand, as a logical implication, that light *must* have mass.

It is often said in text books on particle physics, that photons as such have zero mass; yet we have established conclusively above that the envelope of photons that surrounds a burning star *must* possess some positive mass. Indeed from all we have argued above, we can say what its mass must be: it must be exactly equal to the mass of that portion of the star's matter which was converted to photons in the star's interior during the period that star was burning.

## THE DISTRIBUTION OF LIGHT

In the case of most stars, when the star "dies", or stops shining, a very considerable percentage of its initial mass is obviously going to end up in the form of photons. This envelope of photons, or light, must perforce surround the dying star, with most of its mass concentrated nearer the star (where the photon density is greatest) and falling away in proportion to the square of the distance from the star (assuming the star has been burning at a constant rate). Nevertheless, its mass has to extend for as many light years as the number of years the star has been shining. That's because the light will have travelled in *x* number of years a distance of exactly *x* number of light years.

Take for instance our own sun. It has been shining for 5 billion years or so, and is expected to shine for another 5 billion or so before transforming itself into something else – that is to say, a form which would be unrecognisable to anyone who had seen the sun as it is today. So even today it is surrounded by a spherical envelope of light, or photons, about 5 billion light years in radius. Of course, the photons at the outer limits of this envelope are very thinly spread out, and so have a very low density and thus low detectability. Photon density in regions closer to the sun is obviously much greater.

Five billion years or so from now, when the sun will have become something else, that something else (whatever it may be: white dwarf, "brown dwarf", or whatever) will be surrounded by a bubble of photons having a thickness of 10 billion light years or thereabouts, expanding at the speed of light into the rest of the universe. Inside this bubble will be a spherical region empty of *sun*light as we know it (though of course the light from other stars will still be there; and there may also be light from whatever that "something else" happens to be at that time, which may be luminous too: though hardly as luminous as it is today). This region empty of sunlight will also expand at the speed of light. At that time, or later, any sentient beings which happen to be inside this bubble will never see our sun's light, and, if whatever has remained of the sun is also "dark", may never even know that our sun existed: to them, our sun will have become a non-entity, unless, like us, they are logical enough to *infer* that our sun must have existed at some time in the past, and is still contributing the mass of the universe as a whole.

At the very least, the photons surrounding the region which is empty of sunlight will still retain their mass, and that mass will be virtually equal to that portion of the sun's matter which will have been converted into light over the lifetime of the sun. (We say "virtually" and not "exactly", because a tiny portion of sunlight will have fallen on other astronomical entities like planets, asteroids, comets, interstellar gas, and even on other stars; and of that tiny portion, an even smaller portion will have been absorbed by these entities).

Now if one takes into consideration, not just all the stars there are, but all the stars that ever were, it is obvious that they must have generated a great many photons. And since all these photons are all still there somewhere – even if we (like the above-mentioned hypothetical aliens) can't see them and maybe never will – these photons *must* contribute significantly to the total mass of the universe.

It should be abundantly clear, therefore, that even to *expect* that the mass of the universe ought to equal the mass of the luminous matter alone, is illogical.

## This Mass of Photons Not to be Confused With The Microwave Background Radiation

By the way, the photons mentioned above are not to be confused with the photons comprising the microwave background radiation, which is thought by many theorists to be a remnant of the "Big Bang", and which pervades space extremely smoothly, reaching us uniformly from every direction. (It may not actually *be* a remnant of the "Big Bang", but that makes no difference to the argument made here). The microwave background radiation is a smooth sea of photons, reaching the earth almost perfectly uniformly, with a variation of less than one hundredth of one per cent. It certainly can be detected, and of course also contributes to the total number of photons in the universe.

However, the majority of the photons given off by all the stars that have ever shone are *not* detected and most likely never will be, since most of them are moving in a direction that does not, and never will, end up in our eyes or instruments.

(We have to say *"most likely"* because, who knows? – humanity may in some distant future find a way of travelling at "warp speed" – as in *Star Trek* – and catch up to these photons which are travelling away from us at the speed of light. Even though the presently-known laws of nature preclude that possibility, it doesn't mean that the laws we have discovered to date are absolute.

(Indeed it is has been quite clear for several decades now that both General Relativity and Quantum Mechanics – two of the most strongly-established and widely respected theories in physics today – must be incomplete, since they don't seem to agree completely with each other, even though they do seem to agree with most observations; and that both will, therefore, likely be supplanted by better theories at some time in the future. Besides, of all scientific theories, it is only Relativity which requires the speed of light to be the maximum speed that can be attained. No other scientific theory demands that, not even Quantum Mechanics (by itself). So if Relativity itself is flawed, maybe the speed of light is *not* the universal speed limit.)

## Further Support For The Above Conclusion

A consideration of the distribution of the mass around galaxies, as calculated by the motion of the stars and gases in them, also supports at least part of the above conclusion. The calculations indicate that if gravity alone is responsible for the shape of the galaxies, each galaxy must be surrounded by an envelope of mass concentrated near the core of the galaxy and falling away gradually with distance, but extending quite a bit beyond the (visible) outer edges of the galaxy. This is consistent with the conclusion reached above, namely that the photons given off by the stars that comprise – and, in the past, used to comprise – the galaxy in question must contain a great deal of mass. This is all the more so since such photons, too, must be concentrated near the galactic core and would fall off in concentration as they move away from that core, extending, however, well beyond the outer (visible) edges of the galaxy.

The falling off cannot, however, be inversely proportional to the square of the distance, as would be the case if all the stars in the galaxy had started shining at the same instant of time. This is because the photons farthest away from the galaxy would be such as have been generated by the galaxy's oldest stars: photons from younger stars cannot have had time to reach that far. Older stars in any particular galaxy could have been fewer in number than the rest of the stars in that galaxy: and if that were the case, the light farthest from the galaxy has to be considerably less dense than would be predicted by a simple inverse-square law. On the other hand, if the oldest stars in a galaxy (most of which could have stopped shining by now) were greater in number than the stars visible in that galaxy today, then the light farthest from the galaxy would be *more* dense than would be predicted by an inverse square law.

But maybe – as some theorists, including Hannes Alfvén, point out – gravity is not the only force at work in shaping the galaxies: that electromagnetic forces, working in the plasma which must pervade space (about the existence of which we shall have much more to say later on) – that these huge electromagnetic forces, which must exist in space, and which are enormously more powerful than the force of gravity, are responsible for giving the galaxies the relatively compact shape they possess today.

But this theory can also be accommodated in our argument, if it is borne in mind that in a very old galaxy, photons from the oldest stars in it may well have reached the farthest reaches of the visible universe, which seems to be about 15-20 billion light years away from us, or even farther (if there is any farther). But since the photons would at that stage fill such a huge space, their density would be extremely low: very likely so low that they would most probably be undetectable even if they were to enter our eyes or our instruments. Their diffuse nature would, in all likelihood, play little or no part in gravitationally shaping the galaxies.

*But the photons would still be there,* flying around *somewhere;* and thus would contribute to the total mass of the visible universe.

## THE SIZE OF THE UNIVERSE

By the way: we have to say "*visible* universe" and not "*the* universe" above, because we have no idea how large the universe really is. Some theories of the universe – including those which postulate that the universe is finite, such as those based on the so-called "inflationary universe" model – predict that the universe may be as large as $10^{1,000}$, or even more, times larger than the 15-20 billion light years horizon we can observe. This is a figure so enormous as to be quite mind-boggling. No star we see – or can even theorise about – could shine for that many years: it would use up all its nuclear fuel long before that time is up, and become a completely dark body.

If, on the other hand, the universe is actually infinite, it becomes even more mind-boggling (as I have discussed at much greater length in another essay, entitled *Metaphysical Implications of Cosmology*). For one thing, the mass of an infinite universe would also be infinite, but would be distributed over an infinite volume: which would imply, among other things, that the density of the universe cannot be known – infinity divided by infinity being a calculation not allowed by mathematics (at least as we know math to be; but maybe someone will develop a better math in the future, capable of accommodating infinity-divided-by-infinity as well).

It should be obvious, of course, that if the universe really is infinite, one could never actually *know* that fact by any evidence based on observation. If the signals for making those observations travelled at any finite speed at all, even "warp speed", they would still take forever – literally – to get here from all over an infinite universe: and we really don't have that much time.

And even if an infinite universe is also eternal – in other words the signals *have* had forever to get here – they would nevertheless be infinitely faint by the time they arrive, so we couldn't possibly detect them. This is because Quantum Theory requires that every signal – indeed every*thing* – exists only in finite bits, called quanta, and it is impossible to have less than one whole quantum of anything. If a signal is so faint by the time it reaches earth that it has dwindled to less than a quantum, it cannot be detected at all, not even (theoretically) with the most perfect of instruments.

And besides, although one might postulate that signals travelling at infinite speed *may* be discovered some day (like tachyon rays, for instance), it still doesn't remove all the difficulties inherent in thinking about an infinite universe: for infinite speed implies all sorts of weird things, like being in two places at the same time, or even being everywhere at once.

These are serious problems with postulating an infinite universe, and there are others as well, too numerous to mention here; and one is hard pressed to see how they could be overcome by science, or even by logic.

One is certainly entitled to *believe* in an infinite universe – the above argument doesn't prove the universe is *not* infinite – but it does seem to indicate that one would have to take the existence of an infinite universe on faith, like the existence of the Almighty. Such faith is beyond the scope of science and logic as we know them (but maybe someone will develop better science and logic in the future, capable of accommodating faith as well).

There is no point, however, taking such large universes – whether finite or infinite – into consideration in *this* essay, because under such conditions we would never be able to figure out the effect, on our own corner of the universe, of objects beyond our ken: and if that's really the case, we might as well give up the study of cosmology as being inherently hopeless.

For the present, therefore, let's stick to a universe more or less the size we know it: about 15-20 billion light years across, or maybe a little more, but not a lot more.

## Photons Generated By Quasars

Now returning to our earlier arguments: it should also be clear from everything we have said above, that the photons pervading the universe would be such as have been generated, not just by the stars, but by other astronomical entities as well. For instance, it is thought by most astronomers that a great many quasars used to exist billions of years ago, each quasar shining with the brilliance of a great many galaxies: as many as ten-thousand or even a hundred-thousand galaxies, according to many estimates. (We have to say they "used to" exist, because all the quasars observed by us seem to be at a distance of many billions of light years from us – which means that they must have all existed many billions of years ago. There are none observed very close to us, which seems to indicate – though does not constitute absolute proof, admittedly – that now, or in the recent past, they do not and did not exist. Since the universe itself is thought by most cosmologists to be 15 to 20 billion years old, this means that the quasars we have actually observed must be some of the oldest things we know about.)

Just because all the quasars we have observed seem to be billions of light years away from us does not mean, of course, that there were none nearby at some time long ago: it only means that we don't *see* any nearby right now. Billions of years ago, quasars may well have existed in our neighbourhood (we can hardly say "near us" or "near our sun", because neither we nor our sun existed at that time). In fact it seems reasonable to suppose that quasars *did* exist at one time in our neighbourhood of the universe too: it seems a bit far-fetched to think that all the quasars that ever existed were only located far, far away from us – that would imply something very special about us from the point of view of the universe, and there doesn't seem to be anything special about us from anyone's point of view except possibly our own.

Now if the quasars in our neighbourhood burned out long, long ago, we would, of course, never see their light: it will have left our neighbourhood long, long ago too. *But that does not mean they did not exist at one time: it just means we don't see them now, and perhaps never will!*

It is clear, of course, that if quasars existed only long long ago, by now they must have turned into something else, even if that something else is entirely composed of photons and black holes. Some astronomers contend that each quasar used to have a very massive black hole at its centre, and indeed was powered by matter falling into the black hole, which would generate enormous quantities of light. After the quasars stopped shining, these black holes, if they actually existed, would still be left behind: and so, of course, would the light generated by matter falling into them. If so, it could well be that *everything* those quasars consisted of billions of years ago has by now turned into "dark matter". All those burned-out quasars would, therefore, be quite invisible; but as we have quite conclusively established above, the mass they possessed initially must still be in the universe somewhere.

Some theories of the universe imply that the quasars, after they burned out, gave rise to the galaxies we see today: in other words, that galaxies are remnants of quasars that "died" long, long ago. If so, according to our above reasoning, the mass of all the galaxies must be enormously less than the initial mass of all the quasars that gave rise to them: that is to say, by at least as much as the mass of the light that has by now left our neighbourhood of the universe. If each quasar shone with the brilliance of ten-thousand or a hundred-thousand galaxies, then, that light would have a mass ten-thousand to a hundred-thousand times greater than all the light given off by all the luminous matter in all the galaxies we see.

Whatever the remnants of the quasars are, all the photons given off by all the quasars that ever existed must, in any case, also contribute to the total mass of the universe. We have no absolute proof as to how brightly quasars really used to shine, or for that matter how many there were; but if they used to shine as brightly as many astronomers suspect (and as is actually observed, at least regarding the far-away quasars we can detect), and if they were as numerous as all the galaxies that exist today, they must by now have generated so many photons that the total mass of such photons must surpass, perhaps by many orders of magnitude, the mass of all the photons generated by all the stars that ever shone. (Further on in this essay we shall be discussing the hard figures implied by such arguments).

But because of their extreme age, many of these quasar-generated photons must by now have spread very far away from us, and thus we'll probably never see them or hear from them again, even if we some day develop "warp drive" like on the Starship *Enterprise*: after all, even the Starship *Voyager* – supposedly more advanced than the *Enterprise* – is only said to be capable of reaching the other end of our own galaxy after 75 years, and that too at maximum warp! (Perhaps if we could find some nice "worm-hole" ending 15 billion light years away or thereabouts, we'd be able to catch this quasar-generated light).

No matter what, the above reasoning demonstrates conclusively that quasar-generated photons too must contribute *something* to the mass of the universe: very possibly, contribute a great deal.

## THE CURVATURE OF THE UNIVERSE

Now a question may arise: which way are those photons headed? (This should also give us an idea as to why we can't see them). Relativity tells us that space (or more accurately, space-time) is curved. However, Relativity cannot tell us whether that curvature is positive or negative – that is, whether space-time is curved so that parallel lines in space will after some distance meet, as on the surface of a ball, or whether they will move farther and farther apart with distance, as on the surface of a saddle. Nor does Relativity tell us conclusively how great the curvature of space-time is: that is, what is the "radius", if one may so think of it, of such curvature.

There are at least three theories of the universe, all of which satisfy Relativity: one, that space-time is curved positively, in which case all light will one day return to its source; two, that space-time is curved negatively, so that light, once emanated, will keep on going in a somewhat curved trajectory; and three, that space-time is curved only locally, due to the local presence of matter in it, but on the large scale it is flat (somewhat like the surface of a lake when a wind is blowing, which if examined from up close shows lots of waves and ripples, but if viewed from a distance appears quite flat). In this third instance, light would move away from its source forever in pretty much a straight line, though its trajectory may curve this way and that locally at different points thereon.

Which of these models describes the real universe depends on the amount of gravity generated by everything in the universe. This, in turn, is dependent on the amount of mass possessed by the universe as a whole. If the mass of the universe is below a certain critical figure, space-time will be curved negatively, while if it is above that figure, space-time will be curved positively. If it is, on the other hand, exactly equal to this critical figure, space-time will be flat, at least on the largest scales.

Some models of the universe imply that the third of the above alternatives describes the real universe: in which case the light from all the quasars will be moving away forever in more or less straight lines, although it may depart from the straight path locally. As far as simple observation goes, the observed amount of (visible) matter implies that space-time is curved negatively, in which case light from quasars will also continue to move away forever from its source, but in somewhat curved lines. However, as we have seen in this essay, visual observation alone – without, so to speak, the input of some serious logical thought – is unreliable in determining the mass of the universe, since all we can observe is luminous matter. If there is dark matter we could not observe it, but would have to deduce its presence.

In any case, if space happens to be either negatively curved or flat, light from quasars will never return, so most of it we'll likely never see (unless we find that worm-hole about which we jested earlier).

However, if space is curved positively, light from early quasars will one day return to where it originated; and if it originated around here, it will return to our neighbourhood of the universe. But *when* that will be depends on how strongly curved space is: that is, its "radius", so to speak. Even if space is positively curved, its curvature may be so large that light from these quasars which shone so very long ago, may nevertheless not have had enough time to go all the way round the universe and come back to its source.

All the above therefore implies that no matter which model of the universe actually fits the facts, light from most of the quasars – except those which were very far away from our neighbourhood of the universe – must still be moving in a part of the universe to which we have no access, and most probably never will. *Yet it must still be there!* So it must, perforce, contribute to the mass of the universe.

## PHOTONS GENERATED BY HOT GAS

Then there is the light emanated by hot gas, which is thought to pervade large portions of the universe, especially in the vicinity of large galactic clusters and superclusters. Although its density is very low, such gas occupies a very large amount of space: and therefore is not inconsiderable in the total picture. It also gives off light, due to its heat. Some of this gas is thought to be so hot that it has a temperature of millions of degrees Kelvin. Of course, due to this high temperature, the light given off by such hot gas is in the X-ray portion of the electromagnetic spectrum: but even so, it must still consist of photons. Indeed, due to the fact that the energy of short-wave-length light is much higher than that of long-wave-length light, these X-ray photons must have a great deal of mass (this again follows from Einstein's equation $E=mc^2$, or rather, from its derivative $m=E/c^2$: since in this equation if E is large, so is m). Thus these X-ray photons could also contribute significantly to the total mass of the universe. (The hot gas itself, of course, would contribute to the total mass of the universe, quite aside from the photons it generates; but that would be another matter ... quite literally).

There is, actually, considerable debate as to what force is responsible for generating this enormous heat. The conventional theory goes that the heat is generated by gravitational collapse. However, the temperatures observed – millions of degrees Kelvin – cannot be accounted for by mere gravitational compression. The same high temperatures occur in coronas (such as that of our sun). It *is* possible, however, to have such high temperatures generated if electromagnetic forces are taken into account. This would imply that the gas is, actually, a plasma: that is, the electrons are stripped from the nuclei of the atoms that make up the gas (which is mostly hydrogen, according to the spectra detected). This conclusion is inescapable if we assume the temperatures to be generated by electromagnetic forces, since magnetic fields can have very little effect on atoms where all the electrons are bound to the nuclei.

If so, it would also imply the presence of plasma elsewhere in space. This is not a notion accepted generally by cosmologists, except for a few who espouse the plasma-dominant theories of the development of the universe. But some thought should convince us that the idea is not so preposterous, because we know that the sun spews plasma into space at a phenomenal rate. Some of it actually reaches the earth, where it spirals down into the atmosphere along the earth's magnetic field lines, namely near the north and south magnetic poles. This causes the aurora borealis in the northern hemisphere and the aurora australis in the southern. (Charged particles cannot cut across magnetic field lines, because of the effect of the magnetic field on their electrical charges, and that is why we do not see the aurorae except near the poles). This also proves that the particles are charged: in other words, the material spewed out from the sun exists as a plasma.

None of this should be very surprising; for after all, the interior of the sun and all the stars consists mostly of plasma. It is within the plasma that stellar fusion takes place, and indeed that is why scientists have been trying to create plasma in the lab with the help of tokamaks and other plasma-containing devices: to initiate controlled fusion on earth!

The fact that the plasma from the sun reaches the earth shows that the particles of which it consists have considerable velocity. Indeed their velocity must be in excess of that required to escape the sun's gravitational pull. Which in turn means that over the long period the sun has been shining, at least some of the plasma must have escaped into interstellar space. And since all stars must spew plasma into space like the sun does, surely there is an enormous amount of plasma floating around there, quite invisible to our telescopes.

(*Of course* it must be invisible to us, since even the plasma spewed out by the sun is invisible! It only becomes visible, in the form of the aurorae, when the charged particles strike the earth's atmosphere. The rest of the time it allows a totally unobstructed view of the sky, at night as well as during the day).

Thus even if one theorises, like Alex Lerner and Hannes Alfvén, that the dominant forces shaping the known universe are electromagnetic and not gravitational, there *must* be dark matter, in the form of plasma at least. And since the plasma must also be heated by the electromagnetic forces, this heat, which is of course radiated away as light (visible or otherwise), must also possess mass.

Anyway, with all the above in mind, it seems logically quite untenable to assert – as Stephen Hawking and others do – that electromagnetic forces play only an insignificant part in the shaping of the universe, if at all. They may not be the only forces, maybe not even the dominant ones; but they surely *must* play a highly significant part.

## Photons From Early Stars

Many astronomers suspect that many billions of years ago, before the formation of the present generation of stars, a great many very massive stars were initially formed. (This is hypothesised to have happened after the "demise" of the quasars, but before the formation of the galaxies as we observe them today). These stars, being so massive, were also very fast-burning, and therefore short-lived: and by now – or so it is thought – they have all burned out. (A very massive star has a great deal of gravity, and thus the pressure at its centre is much greater than in a lighter star: and this great pressure greatly accelerates thermonuclear reactions, which causes the star's fuel to burn up very fast. Even though it has a great deal more fuel than a star the size of our sun, its rate of burning is so *much* greater that the fuel burns up very quickly compared to the rate of burning of the fuel in our sun.)

Whatever remained after these massive stars in the universe of that epoch burned out – or so these astronomers think – eventually became the stars we know today.

This is all very well, but if the hypothesis is correct, these conclusions can't be *entirely* correct. Among whatever it was that remained after these stars burned out, there must have been huge amounts of light; and this light cannot all have been used up to form the galaxies we see today. This is because it would have been impossible to trap most of that light with the force of gravity of the emerging galaxies: the velocity of light is well above the escape velocity of every galaxy known. Even that portion of the light which actually fell on the surface of a star cannot have *all* been trapped, because some of it would bounce off back into space (just as some sunlight bounces off the earth, the moon and the planets).

So most of that light must still be out there somewhere: due to its enormous age, it is probably floating around in the huge voids between the galactic superclusters. (The present map of the known universe seems to indicate that most of the luminous matter in the universe is concentrated in extremely large super-clusters of galaxies, all of them stretched out in space like the "soap film" in the bubbles of a vast foam bath, with the rest of space consisting of “voids”, somewhat like the inside of the bubbles of a foam bath, except that these voids don’t contain any air. But, as we have seen above, they can’t be totally empty of *everything,* because they must contain vast quantities of light.)

It’s tempting to try and make a calculation of how much light those very massive stars must have put out, at least in comparison with the light produced by stars like our sun. (We shall avoid, for now, the inclusion of hard figures into our discussion, though we shall try a little later to make more precise calculations). These stars have a life span of about a hundred-million years. Now this may seem like a long time to us, especially when waiting in line at the post office, but in terms of the “lives” of stars it’s a mere instant. For example, our sun has already existed fifty times as long, and will exist another fifty times longer. Thus, a hundred or more generations of these very massive stars could be “born”, shine and “die” in the time it takes for a star like our sun to “live” just one “lifetime”.

Now this allows for an astoundingly enormous amount of light to be produced by such stars. This is because if there were many generations of them, each preceding generation would have had to have possessed a greater total mass than its succeeding generation, by an amount equal to the “dark matter” produced by the previous generation. And since, as we have seen above, much of this “dark matter” would have been light, a larger amount of “dark matter” (including light) would have been produced by each previous generation than by each succeeding generation. (In this regard, we shall prove further on that there must be more to the “dark matter” than just light).

For instance, if these massive stars was as numerous as the stars visible today, and if there were a hundred generations of them, and if (very conservatively) only two per cent of each star’s mass were converted into “dark matter” during each generation, it would still imply that the very first generation must have possessed a total mass about eight times that of all the luminous matter visible today! And since none of that original mass could have “escaped” from the universe (where in heaven could it go?), it must still be there somewhere, in some form: as light, black holes, neutron stars, products of supernova explosions, or whatever.

Indeed if so much light (and other kinds of “dark matter”) was actually produced by these early massive stars, it might well account for enough mass to one day reverse the expansion of the universe. (With the amount of luminous matter detected at present, it seems that the universe would be destined to expand forever: there is not nearly enough luminous matter to generate a gravitational field strong enough to halt this expansion).

Of course we have no idea how many these very massive stars were, how many generations they were, or how long they shone; and in fact we may never know. But the above argument goes to show that there *could* have been enough “dark matter” produced by such stars alone – leave aside the quasars – to account for all the mass supposedly “missing” from the universe.

## OTHER KINDS OF EMANATIONS

Stars, quasars, hot gas, and other astronomical entities give off, not just light (or photons), but other kinds of emanations as well. These include cosmic rays, neutrinos, even material comprising coronas and stellar wind (like those of the sun) – all of which leave the entity in question and fly off into space at escape velocity or greater, and thus never return. It stands to reason that all of these, emanating from every star that ever shone, every quasar that ever quased, every bit of hot gas and everything else that ever emanated anything – all these emanations must still be floating round in space somewhere. Most of these will never be detected, since they are moving in every direction *but* towards us; but they must exist, and therefore must contribute to the total mass of the universe.

In fact *anything* emitted by a star at any speed above its escape velocity will fly off from that star, never to return. Some of it may, of course, be captured by some other star’s gravitational pull; but if the initial velocity is above the escape velocity of the star’s “home” galaxy itself, then these emanations will even end up outside that galaxy.

How much they contribute to the mass of the universe is of course quite uncertain – neutrinos, for instance, weigh next to nothing, and it's very hard to figure out how many there are in the universe – but if they contribute anything at all, this contribution ought to be taken into account when estimating the total mass of the universe.

Many of these emanations travel, if not quite at the speed of light, then close to it. These include, for instance, cosmic rays (which are basically a whole mix of elementary particles, moving close to the speed of light). Because of their speed, they acquire quite a bit of mass. (This is a consequence of Relativity: since in order to move that fast they have to acquire energy, that energy shows up as mass, according to $E=mc^2$. We shall discuss this phenomenon at greater length later on.) Now this increase in mass must also show up as an increase in gravitational force.

Thus even neutrinos, which at rest possess no mass or virtually none, could acquire mass as a result of their velocity. The faster they move, or rather, the closer to the speed of light they get, the more mass they would acquire. Now this phenomenon may also account for a large amount of the total mass of the universe. Neutrinos do not interact with matter very well – for instance, they pass right through the earth as if it were mostly empty space (which, in point of fact, it is, as any physics text book will confirm); but the *mass* they possess must interact with ordinary matter just like any other mass would, namely gravitationally.

Now it is not at all clear how many such particles are given off by stars *unlike* our sun, or by other emanating bodies like quasars or hot gas. In the case of quasars especially, we have really very little knowledge about the mass of such emanations. Nevertheless, as we have shown here, these emanations *must* exist somewhere in the universe, and obviously they would be invisible: that is to say, they would be "dark matter". And if their initial mass was considerable, so, too, must their present mass be.

As for their distribution, they cannot spread as far from the originating star as can light, since they do not travel at the speed of light, but only above the star's (or at best its galaxy's) escape velocity. This can be *extremely* low compared to the speed of light, and so even after many millions – even billions – of years, the mass of these emanations must remain relatively close to the originating star: at most, in an envelope surrounding the star's home galaxy, extending somewhat beyond its visible outer limits. This again supports the notion, generally held by cosmologists, that much of the "missing" mass of any galaxy lies in a loose envelope around the galaxy in question.

## The Remnants Of Burnt Out Stars And Other Astronomical Entities

Now let's tackle the question of what kinds of "hard" or "lumpy" matter (that is to say, "matter" which is neither energy nor any kind of emanation) must remain behind after a star, quasar, or other astronomical entity is completely burnt out. Most stars, for instance, are not as old as the universe. As we said earlier, our sun, for instance – a quite average star – is thought to be "only" about 5 billion years old, and it is estimated that it has "only" another 5 billion years or so of shine left in it. This would mean that about 10 billion years after its "birth" it will have "died": which is to say, turned into something else. This is much less than the total time the universe has been in existence, which as we also said, is 15 to 20 billion years, according to the best estimates we have at present.

Since a large percentage of stars are like the sun in size and in most other characteristics, it follows that a large percentage of stars which started shining more than 10 billion years ago or thereabouts must have "died", or turned into something else, by now. We already determined that all the emanations they have given off are still in space, and contributing to the total mass of the universe. But what about the stuff left behind?

## The Products of Burning of Very Massive Stars

The very biggest stars, after they burn out, usually end up as supernovas. The material that remains after a star goes supernova is, of course, still there: much of it floating around in space as debris. Our earth itself, as well as our moon and the inner planets of our solar system, are thought to be some of that kind of debris. This is because they contain heavy elements, which cannot be created except in a supernova explosion. (Exothermic fusion – the kind of nuclear reaction that takes place in the normal burning of stars, a reaction which *gives off* energy – can only proceed till the element iron is formed. Elements heavier than iron need an energy *input* to be formed by the fusion of lighter elements; and the quantity of energy input this sort of reaction requires is only available in a supernova explosion).

This supernova debris, like our earth, is “dark”, in that it cannot shine of its own light: it can only shine by reflected light. So most of the debris from supernova explosions – the remnants of the heavier stars – must be in the form of “dark matter” very much like the earth, the moon and the inner planets. Some of it may be in the form of dust, asteroids or comets. At interstellar – and especially intergalactic – distances, this matter would all be “dark” so far as we are concerned: we couldn’t possibly see it, even with our most powerful telescopes.

At the centre of a supernova explosion remains either a very massive black hole or a neutron star. This, too, would be “dark” – indeed it would be hard to imagine anything much darker than a large black hole. (Although Hawking has proved that small back holes must glow with light – called “Hawking radiation” after him – and that this light arises from an effect predicted by Quantum Mechanics, nevertheless large black holes must be almost completely dark, even under Hawking’s theorems).

So when it has completely burnt out, most if not all of the products of the burning of a very massive star would be “dark matter”. Some of it could, conceivably, be brought within the gravitational attraction of a nearby star and incorporated in it, giving the material a new lease of shiny “life”: but the vast majority of it would be left hanging around in space, quite invisible to our telescopes. (This is why we said “*very* conservatively” two per cent, earlier, when discussing the percentage of such a star’s mass that must be “dark” after the star “dies”).

## The Products of Burning of Smaller Stars

Smaller stars do not end up as black holes or neutron stars, but as “white dwarfs”. These do give off light, even if faintly, and will continue to do so for a very long time: for tens or perhaps even hundreds of billions of years. But of course the mass of a white dwarf is much less than the initial mass of the star of which it is a remnant. The rest has all gone off into space.

The above reasoning obviously implies that if, during the time it has existed, the universe has contained a very large percentage of large, quickly-burning stars, then the percentage of dark matter in the universe would be higher than if during that time the universe has contained only average-size stars, or smaller. Large stars would end up almost entirely as “dark matter”, while smaller stars would end up only partially as “dark matter”: in this case, mostly as photons and other emanations.

In any case, a simple “thought experiment” should show that there *must* be at least *some* dark matter in the universe other than light. To conduct this “experiment”, it is only necessary to imagine what the universe would look like after a *very* long time; so long that the time it has already existed is insignificant. (For the sake of simplicity, we will assume that the universe does not possess enough mass to cause it to collapse back upon itself: in other words, on the largest scale the universe is not positively curved).

Well then: all the hydrogen in the universe will have had ample time to be converted into progressively heavier elements, until it is all iron; so there can be no more fusion, at least not the kind that generates energy. In other words, all the stars will have burned out; so there will be no more *star*light. Other kinds of light may still be produced for a while, such as light produced by matter falling into a black hole, or light given off by magnetic fields acting on plasma: but ultimately everything that *could* have fallen into black holes, *will* have fallen into them; and the emission of light from the plasmas will cause these plasmas to cool also. Once they cool, the free electrons will bind again to the nuclei, because there will be no high temperature keeping them apart, while their opposing charges will draw them together; and so there will be no more plasmas left.

All this due to the “arrow of time”: the fact that *some* reactions are *not* the same in reverse as they are in forward motion. The exothermic conversion of hydrogen to helium and then to progressively heavier elements, for example, can go just one way, forwards in time: never backwards. The same applies to matter falling into a black hole: once it has fallen in, there's precious little likelihood of it ever coming out again, at least in our universe. (Relativity, for instance, does not take into account this "arrow of time", and that is another reason to believe it is at least partly flawed).

Therefore, after a very, very long time, what will be left must, of absolute necessity, be just two things: on the one hand, pure energy in one form or another (such as photons, all rushing away from where they were originally produced at the speed of light); and on the other hand, cold, dark matter, in one form or another (such as iron, neutrons, or black holes, floating around aimlessly, moving hither and thither as gravity and momentum dictate). The photons, no matter where they originated, will keep on going farther and farther away from their sources, and so ultimately will all end up on the outer reaches of the universe; and thus the interior of the universe will be totally dark, even if there are any objects in it which could shine by reflected light.

So both the energy and the matter in the universe will be invisible, so far as any sentient beings like us, living in the interior of the universe, would be concerned (if any such beings could survive those extreme conditions). Which means the universe will be totally dark, at least inside. (This is yet another argument against our own universe being eternal: for if it has really existed for that long a period, it ought to have been dark already).

But since the universe has already been in existence for *some* time already, the process that must ultimately end with this final sorry state of things has already had some time to get under way. Therefore we are already getting there!

And as far as the distribution of this "hard" or "lumpy" dark matter goes, it will be clear from both, the above thought experiment as well as plain common sense, that it will remain more or less where the original star (or quasar, or whatever) was to begin with. So from a galactic point of view, its centre of gravity will remain more or less at the centre of the galaxy these objects used to inhabit. This again supports the notion, held by most astrophysicists, that the centre of the "missing mass" of any galaxy lies at the centre of the galaxy itself.

## How Many Photons Are There in the Universe?

At this stage, or even before, a question must surely have arisen in the mind if the reader: exactly how many photons *are* there right now, floating around in the universe? (Let's leave aside for a while the other kinds of "dark matter"). The question, however, is not easy, or perhaps even possible, to answer (though we shall at least give it a try, further on in this essay). It may seem, for instance, a simple task to measure the number of photons that enter a very powerful telescope of a given mirror area, viewing a given angle of the sky, and then averaging out many such measurements. By multiplying the average measurement to take into account the angle of the entire sky, and then by a figure corresponding to the ratio between the size of the telescope's mirror to the size of the visible universe, it may be thought that a good idea of the number of photons in the visible universe may be obtained. But this is not so, as some consideration will easily show.

For instance, if our sun had happened to be located in another part of the universe – say, in the core of a very much larger and brighter galaxy – the figure obtained by the above method would be different from what we would obtain with our sun being where it actually is. In such a hypothetical case, there would be many *more* photons in our vicinity than at present, because our sun would be surrounded by a great many bright stars relatively very close by. The night sky would have been immensely brighter than we see it, and could, conceivably, have even been as bright as day. On the other hand, if our sun had been located in one of those huge intergalactic voids, hanging around in the form of a lone star there, the night sky would have been a lot darker: in fact it may well have been *completely* dark to the unaided eye.

So the number of photons in the universe cannot be determined by simple measurement. As far as I can see, it can only be determined by conjecture. And being conjecture, it cannot be completely accurate. All we can arrive at is a an approximation, accurate to maybe two orders of magnitude. Worse still, unless we can somehow overcome the limitations of Relativity, especially concerning the maximum speed that can be attained, it is probably not going to be possible *even with the best of instruments and measuring techniques* to arrive at a more precise estimate – as we shall see further on. (This is not very satisfactory, certainly: but then nobody ever said cosmology had to be satisfactory).

To begin with, we must realise that it's not enough to take into account only the stars that are visible. As we saw above, many if not most of the photons in the universe may have come from stars – and other entities, like quasars – which have long since stopped burning. If the universe has been brighter in the past – and as we also saw above, some theories of the early universe imply just that – then the number of photons in the universe may well have a total mass many times greater than the mass of the luminous entities visible today.

In order to make this kind of conjecture, therefore, we have to think about the brilliance of the universe as it was in the past: not just the remote past but the *entire* past. And here again, we cannot consider merely those photons, or light, which belong to the visible spectrum. We would have to include *all* photons in our model: radio waves, microwaves, infrared, visible light, ultraviolet, X-rays and gamma rays, as well as electromagnetic waves of even longer wavelength than radio waves or even shorter wavelength than gamma rays (if some model of the very early universe predicts the generation in large quantities of such waves).

And moreover, it may be well to bear in mind that high-energy photons – that is, photons of short-wave-length light – are much more massive than low-energy photons. So if any model of the universe – say, one based on plasma-dominated theories – predicts that large quantities of extremely high-energy photons were produced during any stage in the "life" of the universe, we would have to revise our estimates of the mass of the universe upwards.

Now let's at least attempt to estimate the mass of the light already produced by all the luminous entities that ever shone, even though we know that this attempt is going to be more like a "guesstimate" than a serious prediction. However, let's see if we are even in the ball park. If we find we are, we can at least assume that we are doing well with this line of inquiry, and that it may be profitable to pursue it as time goes on.

To begin with, let's drum up some hard figures, from observations already made by astronomers. The mass of the sun can be calculated from its gravitational pull on the earth, which in turn can be calculated from the earth's orbit: its radius and period. The mass of the sun so calculated is, in round numbers, about 2 x $10^{27}$ tons. The sun converts hydrogen to helium by nuclear fusion, at the rate of 600 million tons a second, or about 2 x $10^{16}$ tons a year. (This is calculated from the present brightness of the sun, using Einstein's equation $E=mc^2$). So in ten billion years, that is to say $10^{10}$ years, it will have "burned" 2 x $10^{26}$ tons of hydrogen, or about one tenth of its present mass. Most of this mass will remain in the sun as helium, but a certain amount will be lost as light.

The conversion to helium causes a loss in mass, as observed here on earth in laboratories, of about 0.75 percent, or 1 part in 133. This is the difference in mass of 4 hydrogen atoms (4 protons and 4 electrons) as compared to the mass of a single helium atom which arises from them by nuclear fusion inside the sun. The helium atom contains 2 protons, 2 neutrons and 2 electrons (2 of the 4 electrons from the 4 hydrogen atoms combine with 2 of the 4 protons to produce the 2 neutrons).

So in ten billion years the mass of the sun converted to light is "only" about 2 x 7.5 x $10^{23}$ tons, or less than one thousandth the present mass of the sun (one part in 1,333 to be more precise). And since the sun is a quite average star, the light put out by all the visible galaxies would also be, in ten billion years, equal to about one-thousandth (to round off the numbers) of the total mass of all the visible stars.

This may sound like an almost negligible amount, since it is not nearly enough to account for all the postulated "dark matter". (Perhaps that is why others have not pursued this line of inquiry in the first place). But it has to be borne in mind that the sun is by no means a first-generation star. All the stars and other luminous entities that burned before the sun also gave out light; and it would appear, from what has been said above, that that light was considerably more than that put out by the sun.

The most powerful generators of light we have observed seem to be the quasars: they each appear to shine with the brilliance of ten- to a hundred-thousand galaxies. And as we mentioned above, it seems quite unlikely that quasars did not exist in our neighbourhood of the universe a long time ago: to propose such a thing would violate the "cosmological principle", accepted by almost all astronomers, that from the point of view of the universe, there is nothing terribly special about us, or for that matter about our earth, our solar system, or even our galaxy (the Milky Way). The reason most astronomers accept the cosmological principle is, that if one rejects it, all sorts of weird things are implied, such as the notion that the universe somehow "knows" where we are. In a sense, of course, it does, since we too are part of the universe, and we know where we are: we're right here! But it's hard to understand how the universe could have conveyed that knowledge to the quasars, especially since they started shining long before we showed up. ("And one more thing: be sure you stay far, far away from that place they're going to be calling Earth in about fifteen billion years, okay? Earth is bad news, real bad – 'specially New York. Try to stay at least ten billion light years away from it, or better still a bit more." Yeah, right.)

If quasars, then, did indeed exist in our neighbourhood – and especially if they were precursors to the galaxies as we know them (as we said earlier, some astrophysical models seem to imply just that) – then the light they must have emanated while they used to shine would exceed the light of the presently-visible galaxies by a factor of ten- to a hundred-thousand. Even at the lower end of that estimate, then, the mass of quasar light already produced, and which must be floating around in space somewhere, would be ten times the mass of all the presently visible stars. And at the higher end of that estimate the light would exceed the mass of the presently visible stars by a factor of one thousand! That higher estimate would be much more than enough to account for *all* the postulated "dark matter" in any model of the universe: in fact it's a bit too much, and implies that the universe should have contracted to a singularity long ago, by gravitational attraction alone.

However, the above calculation assumes that quasars shone for 10 billion years, more or less, and that cannot have been the case: the known universe itself does not seem to be old enough to allow that *and* allow the quasars to get as far away from us as they actually are. But even if they shone for only one-tenth that amount of time (and it seems fairly reasonable to postulate that they shone for at least *that* long), an estimate of the mass of the light they must have emanated over that amount of time would lie (again, in round numbers) somewhere between one and one-hundred times the mass of all the visible galaxies. This, as we pointed out at the beginning of our essay, is exactly the kind of range of "dark matter" mass required by most "Big Bang" models of the universe.

Of course, all this requires quasars to have been as numerous as all the galaxies we see today. Maybe they were not. Certainly they are not observed in numbers large enough to account for such a hypothesis: although being so far away, maybe we have not observed all the quasars that might be observed with more powerful instruments.

However, we have not even taken into account yet the *cause* of the enormous light output of the quasars, which in some astrophysical models requires the existence of enormous black holes, or (in the less-popular theories propounded by the afore-mentioned Alfvén and Lerner) enormous quantities of plasma. Both of these would be, in the main, "dark" as well (even though it is precisely their presence that would have caused all that light to shine); and thus their existence could only push upward any estimate of the mass of "dark matter" in the universe.

And even if quasars were not as numerous as we hypothesised above, we cannot forget the first few generations of very massive and rapidly burning stars that must have preceded our present generation of stars. They also gave out light, and as we saw earlier, that light could well have also been far greater than the light given off by all the presently visible galaxies. Indeed we saw that if there were enough of those massive stars, and if their combined generations lasted as long as, say, five billion years, the total amount of light and other kinds of "dark matter" they generated *by themselves* – leaving aside the quasars – could well have been quite enough to cause a reversal of the expansion of the universe.

So one way or another, no matter which model of the universe actually describes reality, we can see that we are at least in the right ball park.

Indeed we are doing better than that. For if we take into consideration, not just the light, but the other kinds of "dark matter" also, then we have shown that if quasars were really the precursors of the galaxies we see today, *or* if there were enough of those very massive stars in the early universe (these are two very big "if's", though!), then the "dark matter" thereby produced would also be *distributed* more or less in a manner capable of accounting for the (observed) gravitational force of each rotating galaxy – enough to pull its stars inward against the centrifugal force of their rotation around the centre of the galaxy – as well as to account, at least partially, for the clustering and super-clustering of the galaxies as it is observed today. (However, the plasma theories of Alfvén and Lerner seem to account for this super-clustering as well; and it is not yet clear, at least to me, exactly where I should place my bet right now).

It seems, though, that we shall never be able to *exactly* calculate the mass of all the "dark matter" that exists, since we seem to have no way of knowing how many quasars there were, nor how many massive stars there were, nor how brightly they used to shine, and with what range of variation in luminosity. Nor do we have any way of knowing how much matter was emanated, that is to say by way of emanations which were not light; nor how massive were the burnt-out "cinders" that have been left behind in the darkness of space. Indeed we have no way of even knowing how much *light alone* was produced over the entire life of the universe, whether by quasars, massive stars, hot gas, or any other luminous entities. And we might not ever get to know if there were other objects, or for that matter other *kinds* of objects, that emanated light in the very early universe, let alone what else they emanated, and how much of it, nor what else and how much they left behind. (Hey: fifty years ago we hadn't even heard of quasars).

Moreover, the limitations of Relativity, especially regarding the maximum speed that can be attained, preclude our ever catching up to the light that has left our neighbourhood of the universe, and thereby at least getting a rough idea as to how much of it was produced in all the bygone ages of existence.

Thus we seem destined, as far as "dark matter" is concerned, to remain in the dark for a long time, maybe even forever.

And it gets worse: for as we shall see below, there must be more to the "missing" mass of the universe than "dark matter" alone.

## THE MASS OF GRAVITATIONAL ENERGY

One source of mass that has hitherto not been considered in calculating the mass of the universe is the mass of energy: and in particular, gravitational energy. As we pointed out above, according to Einstein's equation $E=mc^2$, energy possesses mass. Now the equation does not specify what kind of energy possesses mass: indeed it says that *every* kind of energy possesses mass. Thus, for instance, two bodies would possess a greater combined mass if separated by a great distance than if separated by a comparatively smaller distance. This is because they would in the first case have greater gravitational energy, albeit initially only in potential form.

This energy would be released – or be converted from potential to real – if the two bodies were allowed to come together by virtue of the gravitational attraction between them. If they were farther apart initially, they would come together with greater final velocity than if they were closer together initially. If the two bodies were two planets, for instance, and initially very far apart, they might come together with so much force that there might well be a tremendous explosion upon their coming together: much greater than the one which is thought by some to have wiped out the dinosaurs, 65 million years ago. That explosion shows how much energy can be released when two astronomical bodies come together.

In that case one of the bodies was just a planet (viz., earth), and the other a mere asteroid: and both of these are, on an astronomical scale, quite puny. Just imagine how much more energy would be released if stars or quasars were to collide with each other.

Now if we consider the two colliding astronomical bodies to be a closed system, then if gravitational potential energy did *not* possess mass, then the two bodies plus the heat and light they generated *after* a collision would have to possess more mass than the two bodies would possess by themselves *before* the collision. (This follows logically from our earlier proof, that light and heat – the latter being dissipated in space as infrared light – must possess mass). This again is an absurd conclusion; and so the above argument proves logically that gravitational potential energy *must* possess mass.

And if one reverses the motions, say by having two (or even more) bodies situated together in a closed system, it would require an *input* of energy to drive them further apart, *against* the force of their own gravitational attraction. This implies, according to Relativity, that when the two or more bodies are driven further apart, their mass must increase by an amount equal to the mass of the energy that was input into the system: the mass of that energy being determined by Einstein's formula $m=E/c^2$.

(If one thinks about it, that's exactly what is supposed to have happened at the "Big Bang". An enormous amount of energy must have been input into the closed system known as The Universe, in order to push all things apart against their own gravitational force. If the "Big Bang" theory is correct, this must have been the largest amount of energy anywhere and any*when*: a record that will obviously stand for all time. (Just where that incredibly huge amount of energy came from, no one knows at present, but that's beside the point right now). Some of that energy was converted into matter as time went on, of course, but a lot of it is apparently still left, since all things are still moving apart from all others against their own gravitational force, and that too at a phenomenal rate. The energy shows up, therefore, as gravitational potential energy. One may refer to it, in fact, as the remnant of the energy of the "Big Bang": namely, whatever remained after some of it was converted into matter, earlier on in the "life" of the universe.)

Besides the above argument, it is also known that gravitational force, *by itself*, can produce heat. The inside of the earth is hotter than the outside, simply because the upper layers of rock are pressing on those lower down; and this pressure is due to gravitational force and nothing else. Similarly, Jupiter, for instance, generates more heat than it receives from the sun, even though it is not large enough to have "ignited" nuclear fusion in its core. In other words, the heat of Jupiter is mostly due to its intense gravitational force, supplemented to a small extent by the sun's rays, which however are quite feeble at that distance. And since heat is energy – and indeed is radiated away from Jupiter in the form of infrared (i.e., light) waves – and since we have already established conclusively that light has mass, the heat generated by Jupiter's gravitational force has mass: and indeed this mass must be equal to the mass of gravitational energy, again as given by Einstein's equation $m=E/c^2$.

Thus Jupiter's gravitational force produces mass, which is as much as to say it *has* mass. And if this argument applies to Jupiter's gravitational force, it applies to gravitational force anywhere.

Now stars and quasars are at this time far, far away from each other. If the universe were not expanding, the gravitational attraction between them would, therefore, ultimately bring them together with immense force. (This hypothetical implosion of the whole universe is sometimes called the "Big Crunch", which is a bit like the "Big Bang" in reverse – not entirely, though, because as far as we know, time really can't be made to go in reverse in every respect, like unscrambling eggs).

No one is absolutely certain whether the Big Crunch will ever come, or not. If there is enough "dark matter" in the universe to increase its mass above a particular limit, the Crunch will come, otherwise it won't. We have seen above that maybe, just maybe, the mass of light itself would be enough to take the total mass of the universe above the limit. But whether that's true or not, the *potential* for the Crunch coming is there, in the form of gravitational potential energy.

Now if one accepts the argument given by Einstein in his Theory of Relativity, and repeated a few paragraphs above – namely that energy, no matter what form it takes, possesses mass – this potential energy ought to possess mass too.

How *much* this gravitationally-generated mass will be, depends not only on the distance between the stars, galaxies and quasars, and in addition the "dark matter" in the universe, but also on the initial mass of these things. Obviously, the greater the present mass of all the things there are in the universe, the greater the "Crunch" would be (if it ever were to come), and so the greater the potential energy contained in all the things that exist. (I deliberately say "things" and not "stars" or "galaxies", so that photons, neutrinos, cosmic rays and other such matter may also be included in the calculation).

However, as we have established above, we have no precise idea how much mass all the things in the universe possess, and perhaps never will, since much of this mass must be in the form of photons which at present are – and for the entire foreseeable future will be – situated in a part of the universe to which we have no access, and maybe never will. So we cannot actually calculate the mass due to the potential energy caused by gravitation, either.

## Mass Generated by Velocities of Objects Moving at Speeds Near that of Light

Now we come to a somewhat tricky part of our argument. According to physics as we know it, in the entire universe there are only three physical properties that are constant – in other words, properties which must have the same value for all observers: namely (i) the gravitational constant, (ii) Plank's constant, and (iii) the speed of light. (Indeed that is why the first two are called "constant", and the third is denoted by the letter "c", which again stands for "constant"). All other physical properties – time, space, movement, position, mass, etc. – are relative: in other words, their value changes depending on who is observing them, and in particular on how fast the observer is moving relative to the observed. (Indeed that is why Einstein's most important theory, which first discussed these peculiarities, is called "Relativity").

Thus Relativity requires that if a person is moving at any speed at all relative to us, his time (as measured by clocks, watches, etc.) would appear to us to be ticking more slowly than ours; his space (as measured by rulers, tape measures, etc.) would appear to us as being contracted, compared with ours, in the direction of his motion; and his mass (as measured by the amount of force it takes to accelerate him by a given amount, calculated by the elementary physics formula f=ma) would appear to us to be greater than what it would have been had he not been moving relative to us. (Actually, to be politically correct, Relativity requires the same to apply for female persons too; but it sounds somewhat silly to repeat all the above with "hers" instead of "his" in all the appropriate places).

However, these relativistic effects become significant only at speeds approaching that of light. Now in normal, everyday activity on earth, in most cases these effects are insignificant, and for practical purposes can safely be ignored. This is because the speeds achievable on earth are, for most large objects, nowhere near that of light. (For very tiny objects, such as elementary particles, this effect has actually been observed on earth, in "atom-smashers" like at CERN and Fermilab). But in cosmology, where speeds of very large objects can actually approach that of light, these effects can't be ignored all that easily.

This is particularly so for objects very, very far away from us. The astronomer Edwin Hubble first demonstrated that the universe is expanding; and by now it has become generally accepted that the farther away an object is from us, the faster it is moving away from us, in direct proportion to its distance. Some of the farthest objects we have detected are, in fact, calculated to be moving away from us at half the speed of light or even faster; and the absolute speed record for any large body anywhere is held by a particular quasar very far away indeed, which seems to be moving away from us at more than 80 per cent of the speed of light. (Do we really stink *that* badly?) Moreover, it is generally accepted that if we were to observe any objects even farther away, say with the help of better telescopes, we might find them moving away even faster: which means, very close to the speed of light itself.

Now this poses a serious dilemma. When objects move at such speeds, Relativity requires that to us, as observers, their mass will appear to be greatly increased, compared with what it would have appeared to us to be, if these objects were not moving relative to us. Indeed Relativity requires the increase in mass to be so great, that the closer the speed of any object – *however tiny that object may be* – approaches that of light, the more its mass (as measured by *us*) would tend to grow towards *infinity*.

(This, of course, ought to be obvious when one thinks about it. If, as Relativity requires, the speed of an object cannot exceed that of light, and if the object is already travelling at close to light speed, no matter how much force one applies to the object, one can only increase its speed by an amount less than the *difference* between its initial speed and light speed. The closer its initial speed is to light speed, the smaller that difference will be, and thus the smaller its *increase* in speed can be. In other words, one cannot accelerate it very much, no matter how much force one brings to bear. And this, if one thinks of the elementary physics formula f=ma, is tantamount to saying that the mass of an object increases due to its speed, tending towards infinity.)

Thus, if there are any objects in the universe – even tiny ones, let alone quasars, which could well be the most massive objects in the universe – moving relative to us at speeds very close to that of light, *their* mass alone could be, according to any measurements *we* make, greater than the mass of all the rest of the universe combined!

This is all the more puzzling because, according to any measurements made *by hypothetical aliens living on those objects*, their mass would *not* be all that great. Indeed as far as they would be concerned, it would be *our* mass that would be tending towards infinity. That is because to them, it would be *us* moving at close to the speed of light. As far as *they* are concerned, they would be stationary.

Then the tricky question arises: how are we to objectively determine the mass of the universe as a *whole*? By our measurements, or by theirs?

Perhaps due to the requirement of Relativity, that mass is not absolute but relative, maybe there *is* no "objective" mass the universe as a whole must possess: in which case the whole "dilemma" of the dark matter is just a figment of the imagination, and the "mystery" doesn't actually need any "solution"! (That *would* be weird, though, wouldn't it).

And on the other hand, if there *is* any real or objective meaning to the term "mass of the universe as a whole", then the above argument poses a very serious dilemma, especially for "Big Bang" theories of the origins of the universe.

This comes about since "Big Bang" theories imply that there *must* be objects in the universe at such a great distance from us, that due to the Hubble expansion of the universe, they would be moving, relative to us, at speeds close to that of light. Our instruments have not yet enabled us to see the "end" of the universe. If the farthest objects we can presently see, which appear to be travelling away from us at about half the speed of light or even a bit faster, are actually the farthest objects there are, then they cannot have had enough initial velocity to have got as far as they are now, from any initial starting point. ("Big Bang" models all require that everything started moving outward from a single point, all at once: indeed that is why it is called the "Big Bang").

In fact all "Big Bang" models of the universe imply that either now, or at some earlier stage in the "life" of the universe, *all* the objects in the universe must have been travelling, *relative to other objects far, far away from them*, very close to the speed of light. That is the only way for "Big Bang" theories to explain how the universe got to be as large as it is now – at least 15 to 20 billion light years across, maybe even more – within the time it has had (namely 15 to 20 billion years, or maybe a little more but not a lot more) since it all supposedly "Banged".

Which implies that at *some* time or other, *all* the objects in the universe had masses (as measured by observers on other objects far away from them) that tended towards infinity. This would follow because *all* the objects in the universe would have had *some* objects so far away from them as to be moving, relative to them, close to the speed of light.

And this implies, therefore, that at some stage or other – either now, or earlier on in the "life" of the universe – the mass of the universe *as a whole* – and thus its gravitational force – must have been tending towards infinity, or pretty darn close!

This, of course, can't *really* have been the case, because if it were, the "near infinite" mass of the universe would have caused it to collapse into a black hole, by the force of gravity alone, long before it got to where it is today. So either the theory of Relativity is wrong, or the assumptions of "Big Bang" models are wrong. Relativity is supported by many, many observations, while Big Bang models are supported by far fewer, so one can easily guess where the smart money is.

But all this is beside the point. Even *now* we see objects so far away from us that they are moving at relativistic speeds. And thus their mass, *as measured by us*, must be increased according to the equations of Relativity. This increase must also, therefore, contribute to the mass of the universe, *at any rate as far as we are concerned!* (And maybe no one else is concerned anyway, so "objective, schmobjective", as Einstein's yiddische mamma might have said).

And moreover, since it is virtually certain that there are objects even farther away than those we have observed (for to claim that we have already observed the entire universe sounds a bit preposterous), and since the Hubble expansion requires these unseen objects to be moving away from us even faster than those we *can* observe, *their* mass must be increased by an even greater percentage, as compared with what we would have observed their mass to be, if they were not moving relative to us.

How *precisely* all this affects the total mass of the universe is not all that clear (especially since we don't even know how many objects we haven't yet seen, let alone how big they are, or for that matter how fast they are moving relative to us); but if it makes any difference at all, it can only *increase* the mass of the universe as a whole: certainly not decrease it. Thus this effect must also contribute to the mysterious "dark matter" of which, by now, we have all heard so much.

## CONCLUSIONS

Let us now determine exactly *what* we have conclusively proved in this essay, how much is left as conjecture, and how much seems impossible to determine even with the best of instruments and intentions.

First, we have conclusively proved that the mass of the known universe *must* be greater than the mass of all the luminous matter (alone) in it. In other words, dark matter *must* exist.

Secondly, we have shown conclusively that light (or to be more accurate, electromagnetic radiation, whatever its wavelength) *must* have mass.

And thirdly, since all the light ever emanated by any entity that emanated light must still exist in the universe, we have proved beyond a scintilla of doubt that it *must* contribute to the total mass of the universe.

Next: since most of this light will never enter our eyes or telescopes, it will be, as far as we are concerned, "dark"So all that light *must* account for at least a portion of the "dark matter" in the universe.

Next: we have proved conclusively that the total amount of light existing at this time in the entire universe *must* be more than the total amount of light at present being produced every second by all the visible entities in the universe, multiplied by the number of seconds the universe has been in existence.

Next: we have demonstrated conclusively that the "dark matter" *must* consist, not merely of electromagnetic radiation, but of other kinds of emanations as well, such as neutrinos, cosmic rays, etc., etc– whatever travels at speeds close to that of light, and causes mass to be generated (as predicted by Relativity) simply due those speeds.

Next: we have proved that there *must* be dark matter in the universe other than emanations and light – namely, the burnt-out remains of nuclear fusion, which is what remains behind after a star stops shining, and all the light and other emanations it generated has fled from it.

Next: we have demonstrated that plasma (in other words, electrically charged particles, such as free electrons, protons, ions, etc.) *must* exist in the universe, since the sun itself is observed to be spewing plasma into space at a horrendous rate, some of it even reaching the earthAnd thus the plasma itself *must* contribute to the total mass of the universe, even though much of it (like that between the sun and the earth) may be quite invisible.

Next: we have demonstrated that since magnetic fields exist around every astronomical body we know, these fields must interact with the plasma to produce vast amounts of energy, using the electromagnetic force which is enormously ($10^{42}$ times) more powerful than the gravitational force. And that energy *must* also contribute to the total mass of the universe.

Next: we have logically demonstrated that the universe must also possess *additional* mass due to the fact that it is so large – in other words, due to the fact that everything in it is so far away from everything else.

Next: we have proved that if indeed galaxies are the remnants of quasars, the amount of "dark matter" that *could* have been produced by every galaxy that ever existed could be enough to account for the clustering and super-clustering of the galaxies as we observe them today.

Next: we have demonstrated that the amount of "dark matter" the universe *could* have produced during all the time it appears to have been in existence would, if all of it had actually been produced, be quite sufficient – indeed more than sufficient – to account for all the mass needed to ultimately reverse the observed (or presumed) expansion of the universe.

Next: we have demonstrated that if "Big Bang" models of the universe accurately reflect reality, there must be objects in the universe whose mass would have increased, due to relativistic effects of speeds approaching that of light, to such a great extent that they alone could account for all the "missing mass" of the universe.

Next: we have demonstrated that, given the limitations of the laws of nature as we know them, and especially the limitations of the maximum speed that can be attained (namely the speed of light), it would be impossible to determine the amount of light existing in the universe – at least observationally; and thus it would be impossible to determine how much the mass of that light contributes to the mass of the universe as a whole.

Next: we have demonstrated that given the limitations of science as we know it, it would also be impossible to determine the total amount of "dark matter" or "missing mass" in the universe as a whole.

The End.