The Location of the Missing Dark Matter

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Abstract. A source of most of the missing Dark Matter is proposed. If the formation of stars was at a time, and in a position, such that the light from them cannot yet have reached Earth, then they are invisible; they could comprise 50% to 70% of all matter in the Universe.

Key words: dark matter: stars: galaxy formation

Introduction

The Standard Model of the Big Bang cosmological model of the Universe states that the Universe is expanding according to Hubble's Law (Peebles *et al.* [1])
$v = H_oR$, where v is the recession velocity of a galaxy at distance R and H_o is the Hubble constant.

If the gravitational attractions of all the masses in the Universe are strong enough, then the Universe should expand more and more slowly and eventually stop and begin to contract and eventually lead to a Big Crunch. If those gravitational forces are too weak, the expansion of the Universe continues forever. There is a critical figure for the average mass density (ρc) of the Universe, where the expansion will eventually slow down and be in balance; this idea is attractive, as it says that our Universe will not expand forever, nor will it eventually contract back into a Big Crunch.

The value of the critical density (ρc) is given as 9.2×10^{-27} kg/m^{-3} by Freedman & Kaufmann [2] (2002). As a measure of that density, the mass of a hydrogen atom is 1.67×10^{-27} kg/m^{-3}.

The critical density of the Universe, below which it would expand indefinitely, would require about 100 times the mass so far located, including the mass equivalent of the total radiation in the Universe (Young [3]). But, there is evidence that there is mass that we cannot discern, and this is termed 'Dark Matter'. The nature and source of Dark Matter in the Universe have yet to be determined. As Freedman & Kaufmann say *"To date the true nature of dark matter remains unknown"*. Hawking [4] (2001) says:

> *Missing mass could also be evidence of the existence of a shadow world with matter in it. Maybe it contains shallow* (sic) *human beings wondering about the mass that seems to be missing from their world to account for the orbits of shadow stars around the centre of the shadow galaxy.*

Recent evidence (Riess *et al.* [5]; Perlmutter *et al.* [6]) supports the idea that the Universe is not only expanding, but is doing so at an ever-increasing rate. As Riess says *"The data favour eternal expansion as the fate of the universe"*. As a result of this research, a new form of energy is proposed termed 'quintessence', which would have the property that its density decreases as the Universe expands (Cowen [7]).

But, a more recent article by Chown (2003) [8] entitled '*Is dark energy a mirage?*'refers to work by Blanchard *et al.* (2003) [9] which gives evidence that this is not necessarily correct and that the Universe is likely to be close to the critical density; they say that the visible matter plus the Dark Matter are sufficient without adding any Dark Energy.

Stars and galaxies are often shown to be pulled together by the gravity of material that is invisible. Some 80% to 90% of the mass of galaxies and clusters of galaxies is estimated to exist in this dark form. Other evidence of invisible matter is in the behaviour of the arms of Spiral Galaxies, which would fly off, were there not some invisible matter to hold them towards the centre of the galaxy. The nature of such Dark Matter is a mystery, but it is suspected that it may consist of elementary particles left over from the Big Bang (Young).

Those two features would account for about 10% of the total missing matter required to achieve the critical density for the Universe. This paper is not concerned with that 10%, but sets out to identify a potential source of some of the remaining 90%, which forms the bulk of the Dark Matter that would yield the critical density figure. The evidence put forward in this paper thus contributes towards the overall average density of the Universe (ρc).

Invisible Stars

A star has to be at a precise distance from Earth, at a precise time in the past, to give a current sighting on Earth at that particular instantaneous position. The position instantaneously occupied must be such that it is at a distance (in light-years) from Earth equal to the years of time that will be taken by an instantaneous light flash to arrive at Earth, if it is to be detected in that particular instantaneous position by an observer on Earth.

A star that was, for an instant, at a distance of 10 billion l-y (10,000 m l-y) from Earth, 6 billion years ago, cannot be observed at that position. The information will not reach the Earth for a further 4 billion years. However, a galaxy that was for an instant at 10 billion l-y distance from Earth, at a time of 10 billion years ago, is now seen at that precise position.

Galaxies contain stars of various ages, but we see a view of a galaxy at a specific time in its history. A galaxy may have acquired or lost stars, of newer or older origin than the bulk of the galaxy, after the light that we currently observe left the galaxy to travel to Earth, but that is unknown to us. If a star formed 10 billion years ago, at a distance of 10 billion l-y from Earth, it will be visible now; but if it later joined other stars to form a galaxy, at a time of 6 billion years ago at a distance of 7 billion l-y from Earth, all that we will see is the original star; the rest of the additional stars will not be seen where the galaxy later formed.

If a galaxy was formed at a time of 5 billion years ago (about the same time as our galaxy) and at a distance of 8 billion l-y from Earth, we cannot view that galaxy now, because light from it will take another 3 billion years to get here. If Earth remains in its present position, relative to the position that was occupied by that galaxy at a time of 5 billion years ago, for another 3 billion years, the signal coming from that galaxy will then arrive at Earth. Any movement of the galaxy, relative to the present position occupied by our Solar System, more recently than 5 billion years ago will not influence the matter. If, however, as seems likely, the position of Earth in Space, in relation to the then position of that Galaxy changes during the intervening 3 billion years, the component of movement, along the line connecting the Earth and the then position of the galaxy, will influence the matter. That galaxy is not ‘Dark’ because it could be seen, if the signal showing its existence had arrived here. It is invisible to us, but is presently visible from other places in the Universe.

The age of the Universe is the subject of continuing debate; Young gives 18 billion years while Willick & Batra (2001) [10] give 11.5 billion years as the age. In this paper we assume an age of 15 billion years; the precise age assumed does not affect the conclusions in this paper.

Our galaxy was formed about 4.6 billion years ago, though some individual stars are considerably older (Freedman & Kaufmann [3]; Van Flandern [11]). Consider (Figure 1) a simplified sequence of the timing of galaxy formation shown in two dimensions as adopted by Young [2].

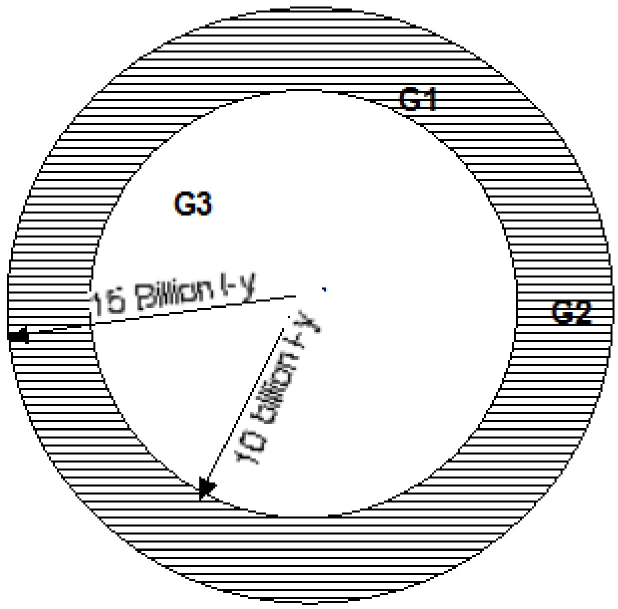

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Figure 1
Universe age 15 billion years; galaxies formed 10 billion years ago

Considering the volume of the complete Universe (15 billion l-y radius), versus the smaller volume of a globular space centred on the Earth, and with a radius of 10 billion l-y, we can calculate the space where galaxies formed 10 billion years ago would be visible or invisible on the Earth at 'E'. We assume uniform distribution of galaxies throughout space. Any galaxy formed at that time (10 billion years ago) at a distance further than 10 billion l-y from Earth, would not yet be visible on Earth, because only 10 billion years have elapsed since the formation of the galaxy. Galaxies G1 and G2 cannot yet be seen, whereas G3 can be seen. Light from G1 and G2 has not had time to reach Earth.

Volume is $4/3\ \pi r^3$; the invisible volume $[4/3\ \pi 10^{27}\ (15^3 - 10^3)]$ is 70% of the total volume of the Universe. Thus, 70% of all galaxies would be invisible as yet upon Earth. The annular space, shown hatched, is where galaxies are invisible. If, on the other hand, the galaxies were formed 12 billion years ago then the volume of space, where galaxies cannot yet be seen, comprises 50% of the total. If all the galaxies were formed at a period between 10 and 12 billion years ago then over 50% of them are invisible. A similar calculation holds if we consider just the birth of individual stars.

Such matter clearly contributes to the gravitational attraction of the total mass in the Universe and should be included when computing the average density. To-date, these invisible galaxies have not been computed because they have not been, and cannot have been, detected. In this respect, they are not 'Dark Matter' but matter that has yet to be seen. Adding in the mass of these invisible galaxies would considerably bridge the gap between the matter detected to date and the critical density of the Universe.

In the case of a galaxy formed 15 billion years ago at a distance of 10 billion l-y from Earth, at some time in its subsequent history it will have reached a place where the distance from the Earth (l-y) will be equal to the time ago (years); this galaxy will have become visible at its actual location in space, at some point in its history. Because nothing can travel faster than the speed of light, that galaxy will remain visible on Earth thereafter. Table 1 shows the % of stars that are not visible, versus their time of formation. Stars formed uniformly throughout the Universe 1 billion years ago are 99.97% invisible. Stars formed at about the same time as our galaxy would be 96% invisible.

Light Cones

Einstein (1922) [12] defined the lower half of the light-cone (Figure 2) as the cone containing points from which a light signal could have been sent, to reach our point 'P'. The lower half of the cone is the envelope containing points that can send information at the speed of light to the point P. To the observer at 'P' nothing other than inside, or on the surface of, the lower half of the cone, can be observed from 'P'. Such light-cones are missing one dimension, and one must imagine the 4th dimension.

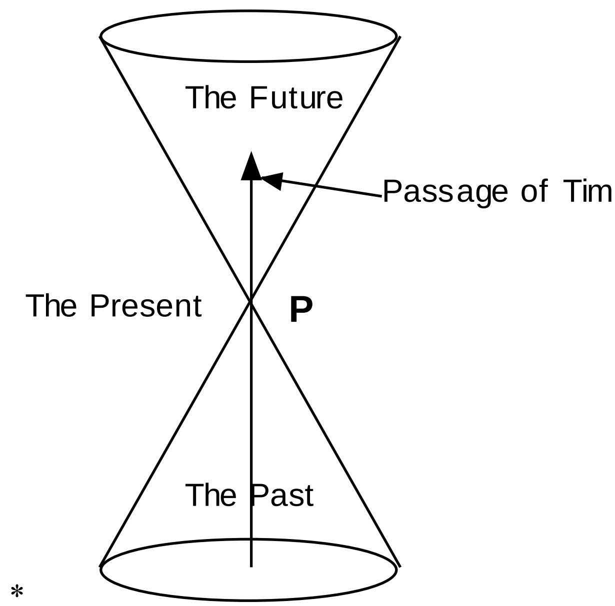

Figure 2
Cone of Light

The top part of the cone is the envelope of what we shall see in the future. Galaxies that are so far away that light from them cannot yet have reached Earth are not contained in the cone. A light cone such as that in Figure 2 assumes that the light-years distance is equal to the years elapsed since the light left the object. But as we have seen, that is not always the case. If the distance (in l-y) from the apex of the cone to the place where a galaxy was created is greater than the time elapsed since the formation of that galaxy, the cone of light does not apply.

All similar light cones for 'observers' at other places in the Universe are expected to have similar amounts visible (because our position is not considered unique).

As shown above, if all stars/galaxies were formed uniformly throughout the Universe, at an average of 10 billion years ago, then 70% of them are still invisible to any one particular 'observer' situated at a particular place in the Universe. It is not the same 70% that is invisible to every such observer; but for each, there is a different 70% invisible.

This assumption, of an average date for the formation of galaxies of 10 billion years ago, does not preclude individual stars or galaxies being formed right back to 15 billion years ago, or in much more recent times than 10 billion years ago. Any star or galaxy, formed near G1 (Figure 1) 11 billion years ago, is visible because the light has had time to get here. The Hubble telescope records such matter.

We cannot add all the objects visible in all of the individual innumerable light cones of all possible observers in the Universe, to get the total matter in the Universe. We can reasonably assume that what is visible in our light cone is typical, and assume that all the other light-cones have a similar amount of matter visible. Some matter, visible in our light-cone upon Earth, will not be visible in many other light-cones. This occurs where the distance (in l-y) from such matter to the other observer is greater than the time in years elapsed since the formation of the object. To get a sum of the total matter in the Universe, we would need to sum all matter, that is visible in the innumerable possible light-cones, for all observation points in the Universe, and which was not recorded in any other light-cone. We should thus count any one piece of matter only once. That would be some task!

Age of Galaxies

There is considerable speculation on the timing and method of formation of galaxies. Ellis *et al.* (2000) [13] suggest that ellipticals can have formed from the merging of spiral galaxies. They say *"close examination of some (but not all) ellipticals reveal tell-tale remnants of recent merging*". On the other hand, Freedman & Kaufmann [2] say *"ellipticals were already well developed 4 billion years ago. ... In contrast, spiral galaxies have been forming continuously over the past 10 to 15 billion years"*. Longair (2000) [14] describes the considerable uncertainty concerning the sequence of events and their timing; he stresses that the global average of the history of galaxies does not necessarily reflect the history of any particular galaxy.

Edmunds (1982) [15] says that it can be argued that the epoch when galaxies formed is *"about 1/5th the age of the Universe"*. There appears to have been an epoch of very active formation at that time.

As better data becomes available concerning the age of the galaxies in general, the percentage of matter that is invisible can be refined. The total amount of such invisible matter in the Universe is considerable, and should be taken into account in the calculation of the average density.

Conclusions

Most stars and galaxies will be visible on Earth only at a later time in their history. This explains where a considerable amount of so-called 'Dark Matter' is located. The average density of matter in the Universe is far higher then presently assumed.

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Table 1

Star or Galaxy formed	% Invisible
12 billion years ago	49%
10 billion years ago	70%
5 billion years ago	96%

1 billion years ago	**99.97%**

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