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RESEARCH ARTICLE

Some Corrections to Measurements of the Ages of Distant Galaxies Using the James Webb Telescope, Due to the Spatial Curvature of the Universe

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Abstract

In this work we have determined the sign of the spatial curvature of the universe during the period dominated by dark energy, that is, from 6 billion years ago to the present, finding that its curvature is positive (k=+1). Thus, during this period, which is the current one, the universe is a closed universe and boundaryless universe, that is, a hollow 3-sphere. Working with an FLRW metric with these curvature characteristics (k=+1), we have shown that a significant error is being made in determining the age of distant galaxies if the spatial curvature of the universe is not considered. A positive spatial curvature, even a very small one like ours, causes the apparent measured distance to not coincide with the Euclidean distance, and therefore, when determining the age by dividing the distance by the speed of light, the times are different. We have found an equation to correct this error and have applied these corrections to the age values of some galaxies, recently determined using data from the James Webb Telescope, which has resulted in significant differences in the age values of some of them, specifically the oldest ones the true ages being significantly lower than the apparent ages given by the telescope.. These corrections for spatial curvature could be key to understanding the existence of very early galaxies in our universe, thus validating the ΛCDM model.

Keywords: Cosmology, Age of the Galaxy, Observable Universe, Spatial Curvature.

1. Determining The Sign of the Spatial Curvature of the Universe in the Present Universe

1.1 Introduction

Given the Friedmann equations, [1], of the FLRW metric, (ρ = Joules/m^3)

$$H^2 = \left(\frac{a'}{a}\right)^2 = \frac{8\pi G\rho}{3c^2} + \frac{\Lambda c^2}{3} - \frac{kc^2}{a^2}$$

$$\left(\frac{a''}{a}\right) = -\frac{4\pi G}{3c^2}(\rho+3p) + \frac{\Lambda c^2}{3}$$

1.2 Equation that Relates the Derivative of the Hubble Parameter with Pressure, Energy Density and the Curvature Spatial

According to the Friedmann equation, the equation of state, and taking into account the expression for the derivative of H, we have

$$H' = (a'/a)' = (a''/a) - (a'/a)^2$$

$$H' = \left(-\frac{4\pi G}{3c^2}(\rho+3p) + \frac{\Lambda c^2}{3}\right) - \left(\frac{8\pi G\rho}{3c^2} + \frac{\Lambda c^2}{3} - \frac{kc^2}{a^2}\right)$$

$$H' = -\frac{12\pi G(\rho+p)}{3c^2} + \frac{kc^2}{a^2}$$

equation of state: w= p/ρ

$$H' = -\frac{12\pi G\rho(1+w)}{3c^2} + \frac{kc^2}{a^2}$$

1.3 Study of H During the Universe Epochs Using this Equation

Let's study the sign of this equation in the different eras that make up the history of the universe. That is, during the radiation era, the matter era, and the dark energy era, which is the current one. Each of these eras

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is characterized by a different value of the equation of state parameter , w, (w=+1/3 in the period of universe dominated by radiation, w = 0 in the period of universe dominated by matter, w= -1 in the period of universe dominated by dark energy), and also according to experimental data [2], currently the term $\Omega_k = kc^2/a^2$ is very small, and its sign is still undetermined.

Furthermore, according to recent experimental data, a trend change in the value of H has been observed as a function of the age of the universe, going from decreasing to increasing since 6 billion years ago. We, studying the equation derived from the values of w and these data, conclude that all these data are fully consistent with the FLRW metric as long as k = +1 is fulfilled, ruling out the other two possible values of k: 0 and -1. We explain this conclusion below.

First, we study the sign of H' according to the different values of w at different times in the universe. We summarize these calculations and reasoning in the following table.

$$H' = -\frac{12\pi G\rho(1+w)}{3c^2} + \frac{kc^2}{a^2}$$

Considering that the curvature term of the Friedmann equation is small compared to the other terms of the equation, the following will be fulfilled.

Period of the universe dominated by radiation, from its beginning until the year 360,000.

$w = +1/3$

$$H' = -\frac{12\pi G\rho(1+\frac{1}{3})}{3c^2} + \frac{kc^2}{a^2}$$

For k = 0, +1, -1. H′ will be negative. H will always be decreasing. It is not possible by this analysis to determine the sign of the spatial curvature in this period.

Period of the universe dominated by matter, from year 360,000 to 6 billion years ago

$w = 0$

$$H' = -\frac{12\pi G\rho}{3c^2} + \frac{kc^2}{a^2}$$

For k = 0, +1, -1. H′ will be negative. H will always be decreasing. It is not possible by this analysis to determine the sign of the spatial curvature in this period.

Period of the universe dominated by dark energy, from 6 billion years ago until its end

$w = -1$

$$H' = \frac{kc^2}{a^2}$$

- For k = -1, H′ will be negative, then H will be decreasing.
- For k = 0, H′ will be zero then H will be constant.
- For k =+1, H′ will be positive, then H will be increasing.

It is therefore in this period of the universe dominated by dark energy that by observing the behavior of H in it we can determine the sign of the curvature in it.

We know from experimental data that for about 6 million years, the Hubble parameter has been changing its trend, from decreasing to increasing. That is, for the past 6 million years, the Hubble parameter has been increasing. This change in trend coincides with the transition from the period of universe dominated by matter to the period of universe dominated by dark energy, the current universe. Thus, according to our analysis of the Hubble parameter, these facts can only be explained if k = +1 in the dark energy period. That is, the spatial curvature is positive in the period of universe dominated by dark energy, the current universe. This prompts us to conduct a more in-depth theoretical study of the universe using the FLRW metric and k = +1, to interpret current cosmological measurements, such as the ages of distant galaxies, which are now being determined and which we analyze below.

2. Some Corrections to Measurements of the Ages of Distant Galaxies Using the James Webb Telescope, Due to the Spatial Curvature of the Universe

2.1 Introduction

The spatial curvature of the universe has been an important objective of study for Cosmology. The Mission Planck [2], measurements of the value of the curvature term in the Friedmann equation demonstrated that the spatial curvature is very small, but they were not able to determine its sign. This sign is very important for understanding the geometric and physical characteristics of our universe (its shape, its boundaries, its energy, etc.).

We have shown that the sign of the spatial curvature is positive (k=+1), for the universe in the period of universe dominated by dark energy, that is, the current universe.

As we demonstrated the relativistic universe with the FLRW metric, with positive sign for the spatial curvature implies, according to reference [3], that the spatial part of its space-time presents the geometric shape of a three-dimensional hollow sphere, that is, a 3-sphere, inserted in a four-dimensional space-time. That is to say, it is a closed universe, finite, without borders, in contrast to the universes of k = 0. -1, which are open universes, that is, infinite.

We assume that in our equations, the total energy of the universe must be the same in the 3-sphere as in the observable universe, and that the energy density must be the same in the 3-sphere as in the observable universe. With this assumption, we therefore require that the surface area of the 3-sphere be equal to the volume of the observable universe.

2.2 Calculations in Cosmology With Spatial Curvature

The 3-sphere geometrically constitutes the spatial part of our spacetime according to the FLRW metric and the positive sign of the spatial curvature. Let's determine its radius, relating it to the age of the universe.

- Determination of the equation of the radius of the 3-sphere
- r is the radius of the observable universe, r = ct
- R is the radius of the 3-sphere
- Volume of the universe = $4\pi r^3/3$
- Surface of the 3-sphere =$2\pi^2 R^3 = S^3$, [4]

Equating the volume of the observable universe with the surface area of the 3- sphere, we have a relationship between the radius of the 3-sphere, R, and the radius of the universe r.

- $4\pi r^3/3 = 2\pi^2 R^3$
- $R = (2/3\pi)^{1/3} r = 0,5964.r \cong 0,6\ r$
- $R/r = 0{,}5964 \cong 0{,}6$
- R = 0,6 r = 0,6, c. t.

In the current universe, the radius of the 3-sphere is.

- t = age of the universe = 13.8 billion years [5]
- $c = 9{,}46.10^{15}$ m/year
- R = 0,6 c t
- $R = 0{,}78.10^{26}$m

2.3 Determination of times in a universe with spatial curvature

In a universe with positive spatial curvature, k = +1, the distance between the universe points P_e and P_o measured by an observer located at point P_o will be given by the length of the spatial geodesic arc of the 3-sphere that passes through points P_e and P_o. Since it is a hollow 3-sphere, it will be an arc of a circle.

The cosmic time, which is the one we are interested in, will be determined by the Euclidean distance between points P_e and P_o divided by the speed of light.

The time determined by dividing the length of the corresponding geodesic arc by the speed of light will not coincide with the cosmic time; it would only coincide if the spatial curvature were zero. This time, determined by measuring the geodesic of the curved space, will be greater than the corresponding cosmic time.

Thus, in the period of universe, which does have positive spatial curvature, k=+1, the times given by telescopes obtained by dividing the distance by the speed of light, do not correspond to the cosmic time that serves as a reference for us.

Let's determine the correction that must be made to determine the cosmic time based on the time given by the telescopes.

To do this, as we have seen, since our universe model corresponds to an FLRW metric with curvature k=+1, that is, a three-dimensional hollow sphere, the spatial geodesic passing through the points P_e and P_o is an arc of a circle, and the Euclidean distance between those two points corresponds to the distance of the arc chord. Thus, the relationship in distances, or in other words, the relationship in times, will be the same as the relationship between an arc of a circle and its chord, that is.

$$t'/t = \frac{sen(d/2R)}{d/2R}$$

where d is the arc length, i.e. the distance measured by the telescope, R is a parameter related to curvature cosmology k = +1, specifically the radius of curvature of the 3-sphere at the moment of observation.

As we saw, for the current universe.

$R = 0{,}78.10^{26}$ m

Thus, this equation, using this data, allows us to adjust the times to the cosmic time scale, that is, to our references. We understand that cosmic time coincides with time in a space with zero spatial curvature.

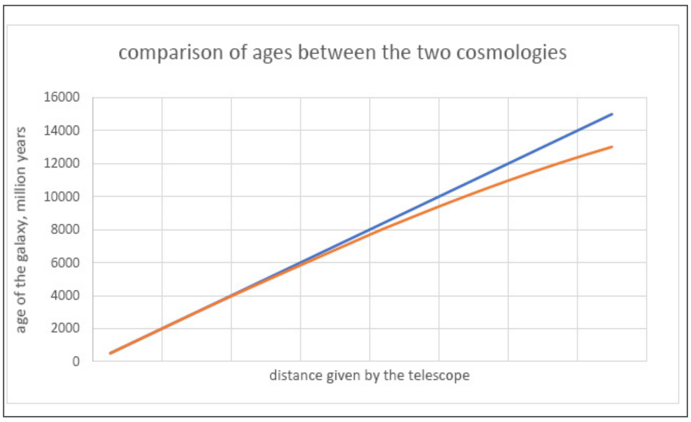

Figure 1. *Comparison of the Ages of Galaxies, Considering Spatial Curvature (Red) and without Considering Spatial Curvature (Blue).*

2.4 Some Corrections to the James Webb Telescope Measurements Regarding the Age of Distant Galaxies

According to reference [6], scientists M. López-Corredoira, F. Melia, J.-J. Wei, and C.-Y. Gao have published age measurements for some distant galaxies, based on data recently obtained by the James Webb telescope. We, in accordance with what is presented here, have corrected these measurements, obtaining lower age values for the oldest galaxies and the same age values as those obtained by the James Webb telescope for the most recent galaxies.

Table 1

	James Webb times	Corrected times	Ages of the James Webb	Corrected age
ID Galaxy	Log_{10} (ageold)	Log_{10} (ageold)	Billion years	Billion years
2859	0,40-0,59$^{+0,64}$	0,40-0,59$^{+0,61}$	2,5	2,5
7274	0,70-1,24$^{+0,34}$	0,69-1,24$^{+0,32}$	5,0	4,9
11184	-0,54-0,46$^{+0,34}$	-0,54-0,46$^{+0,34}$	0,29	0,29
13050	1,04-2,64$^{+0,00}$	1,01-2,64$^{+0,00}$	10,9	10,2
14924	1,04-1,58$^{+0,00}$	1,01-1,58$^{+0,00}$	10,9	10,2
16624	1,04-2,04$^{+0,00}$	1,01-2,04$^{+0,00}$	10,9	10,2
21834	1,04-1,24$^{+0,00}$	1,01-1,24$^{+0,00}$	10,9	10,2
25666	1,04-2,64$^{+0,00}$	1,01-2,64$^{+0,00}$	10,9	10,2
28984	1,04-1,09$^{+0,00}$	1,01-1,09$^{+0,00}$	10,9	10,2
35300	1,04-1,24$^{+0,00}$	1,01-1,24$^{+0,00}$	10,9	10,2
37888	1,04-2,64$^{+0,00}$	1,01-2,64$^{+0,00}$	10,9	10,2
38094	-0,54-0,46$^{+1,58}$	-0,54-0,46$^{+1,55}$	0,29	0,29
39575	1,04-2,64$^{+0,00}$	1,01-2,64$^{+0,00}$	10,9	10,2
ID Galaxy	Log_{10} (ageyoung)	Log_{10} (ageyoung)	Billion years	Billion years
2859	-2,30-0,00$^{+1,30}$	-2,30-0,00$^{+1,30}$	0,005	0,005
7274	-2,30-0,00$^{+1,30}$	-2,30-0,00$^{+1,30}$	0,005	0,005
11184	-1,00-1,30$^{+0,29}$	-1,00-1,30$^{+0,29}$	0,100	0,100
13050	-2,30-0,00$^{+3,00}$	-2,30-0,00$^{+2,99}$	0,005	0,005
14924	-1,60-0,70$^{+0,60}$	-1,60-0,70$^{+0,60}$	0,025	0,025
16624	-2,30-0,00$^{+1,30}$	-2,30-0,00$^{+1,30}$	0,005	0,005
21834	-1,60-0,70$^{+0,60}$	-1,60-0,70$^{+0,60}$	0,025	0,025
25666	-1,60-0,70$^{+2,30}$	-1,60-0,70$^{+2,29}$	0,025	0,025
28984	-2,30-0,00$^{+1,30}$	-2,30-0,00$^{+1,30}$	0,005	0,005
35300	-2,30-0,00$^{+1,76}$	-2,30-0,00$^{+1,76}$	0,005	0,005
37888	-1,60-0,70$^{+2,30}$	-1,60-0,70$^{+2,29}$	0,025	0,025
38094	-2,30-0,00$^{+2,11}$	-2,30-0,00$^{+2,11}$	0,005	0,005
39575	-2,30-0,00$^{+1,26}$	-2,30-0,00$^{+1,26}$	0,005	0,005

Thus, according to these corrections, the age interval found among these galaxies at redshift z = 8 narrows slightly, going from [10,9 – 0,005] to [10,2 – 0,005] (billion years). That is, the ages of the oldest galaxies are reduced due to the effect of spatial curvature, which had not been taken into account in their determination. The shift of the interval at its upper edge is 700 million years. A shift that, according to Fig. 1, could reach higher values if the ages of the galaxies were greater.

3. Conclusion

First, we performed an analysis to determine the sign of the curvature of the universe at different epochs. From this analysis, we were able to determine the sign of the curvature during the period universe dominated by dark energy, the current epoch, resulting in a positive sign for the curvature (k=+1). We then developed a cosmology in the FLRW metric with k=+1 and used it to analyze the results being obtained for the age values of distant galaxies. We found that the apparent age of these galaxies may be different from their true age, due to the spatial curvature, which until now has not been taken into account in age determinations. We applied our results to the case of age measurements of galaxies at z=8 by the James Webb telescope, revealing that these corrections significantly affect the ages of the oldest galaxies. From all this we conclude that the spatial curvature of the universe significantly affects the determination of the age of distant galaxies in such a way that their true age is less than the apparent age that is being obtained and this is significantly so as the age of the galaxy increases, being able with these corrections, to make the Standard Cosmological Model (ΛCDM) compatible with the apparent ages of the earliest galaxies currently being discovered.

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