Cosmic Lensing (I) - A new paradigm for Universe expansion interpretation

J. De Vicente-Albendea⋆
Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas (CIEMAT), Avda. Complutense 40, E-28040, Madrid, Spain

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ABSTRACT

The Einstein’s General Relativity theory and the Friedmann-Lemaître-Robertson-Walker (FLRW) metrics define the main equations that rule the history and future of the Universe. The Standard Model for cosmology collects this knowledge along with some other elements as cosmological distance definitions. Thus, the link between the theory and observational data is performed through some defined basic cosmological distances as luminosity distance and angular diameter distance. The comparison between the theoretical models and observational data within the Standard Model has noticed acceleration in the expansion of the Universe. To explain this accelerated expansion, the Standard Model predicts the existence of about 5% of baryonic matter, 27% of unknown dark matter and 68% of unknown dark energy. In this paper, Cosmic Lensing (CL) is presented. CL is a novel paradigm that reveals a new relationship between the luminosity distance ($D_L$) and the angular diameter distance ($D_A$) in an expanding universe given by $D_L = D_A(1+z)$, opposed to the relation $D_L = D_A(1+z)^2$ predicted a century ago and assumed by the Standard Model. The new relation is also deduced from Cosmic Microwave Background (CMB) equations. Formulate linking observational data to cosmological models are redefined accordingly. In consequence, previous cosmology methods and results entrusting on luminosity as observational data must be revised. The expansion rate and the relative densities of the dark components of the Universe as dark matter density and dark energy density should be revised within the new paradigm.

Key words: theory, distance scale, cosmological parameters, dark energy, dark matter, cosmic background radiation

1 INTRODUCTION

During the 20th century were established the foundations of modern cosmology. The field equations of General Relativity were formulated by Einstein (1915), and its application to the Universe stated the basis for further steps. Friedmann (1922), Lemaître (1927, 1931), Robertson (1933) and Walker (1937) (FLRW) contributed to FLRW model, which describes the solutions to Einstein’s field equations for an expanding homogeneous and isotropic Universe whose scale factor varies with time. According to GR and FLRW equations, the evolution and fate of the Universe depends on the nature of different density components, i.e. radiation, matter, curvature and dark energy. Contemporaneously to these achievements, observational evidences of the Universe expansion were found by Hubble (1929); the correlation between redshifts and distances for extragalactic sources was considered the major evidence of the Universe expansion. Doubts about a real expansion were posed by several scientists all along the past century. An alternative explanation known as “tired light” where the photons lose energy on their path to the earth was early formulated by Zwicky (1929). Different cosmological tests were proposed to probe whether the Universe is expanding or remains static. Tolman (1930, 1934) predicted that in an expanding universe, the surface brightness of a receding source with redshift $z$ will be dimmed by $\sim (1+z)^{-4}$. On the contrary, the surface brightness would remain constant or decreasing slower $\sim (1+z)^{-1}$ with distance to sources for a static universe. Large efforts have been devoted to test the Universe expansion following the Tolman guidelines (Hoyle & Sandage (1956), Sandage (1961), Petrosian (1976), Meier (1976), Sandage & Perel-
The discovery of the Cosmic Microwave Background (CMB) in 1964 (Wilson & Penzias (1967)) supports strongly the Universe expansion, and theoretical CMB considerations predict a ratio between the luminosity distance and the angular diameter distance of $\sim (1+z)^2$ which agrees with the Tolman surface brightness prediction for an expanding universe.

Another conclusive test for Universe expansion is the time dilation of Type Ia supernovae light curves that was suggested by Wilson (1939). The results obtained by Leibundgut et al. (1996) and Goldhaber et al. (2001) on this test, strongly supports the cosmological expansion and argues against alternative explanations such as tired light.

A step forward was given at 1998 with the announcement of the accelerated expansion of the Universe. Two independent groups Riess et al. (1998) and Perlmutter et al. (1999) performed careful measurements of the luminosity distance of remote supernovae. The comparison of their measurements to those predicted by GR and FLRW in Type Ia supernovae drove the groups to concluded that the expansion of the Universe is accelerating. In addition, a new relevant component of the Universe was postulated as responsible of the unexpected accelerated expansion, the dark energy. Thus, an universe with approximately 5% of baryonic matter, 27% of dark matter and 68% of dark energy is currently known as the $\Lambda$CDM model within the Standard Model.

In this paper Cosmic Lensing (CL) is presented, a new paradigm for Universe expansion interpretation. Focusing on expansion, CL revises the common live experience of receding light sources where the flux is diluted with distance. On the contrary, the flux from a receding image in an expanding universe remains focused towards the observer and hence it is not dimmed by distance elongation. In this way, Cosmic Lensing re-defines the ratio luminosity-angular diameter distances as $(1+z)$ unlike $(1+z)^2$ defined within the Standard Model, and hence substitutes the surface brightness decay predicted by Tolman from $\sim (1+z)^{-4}$ to $\sim (1+z)^{-2}$. The new relation between luminosity distance and angular diameter distance is also obtained from CMB equations, providing and independent derivation of the new paradigm. The Cosmic Lensing paradigm affects deeply to the Standard Model of cosmology and the conclusions of many previous studies should be revised.

The rest of the paper is organized as follows: in Section 2 some basic definitions on Standard Model are reviewed. The Cosmic Lensing paradigm is unveiled in Section 3 along with its effect on cosmological equations. Finally, the conclusions are presented in Section 4.
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Figure 1. Standard Model: Relation between angular diameter distance ($D_{A}$), comoving distance ($D_{C}$) and luminosity distance ($D_{L}$) for a flat universe. $D_{A}$ is the distance at emission, $D_{C}$ is the distance at reception and $D_{L}$ account for the distance elongation due to Universe Expansion ($\sim (1+z)$), time dilation and wavelength redshifting ($\sim (1+z)$). The relation $D_{L} = D_{A}(1+z)^2$ can be deduced from the figure.

where $D_{A}$ is also the distance to the object at time of emission. There are four $(1+z)$ factors affecting to flux energy diminution (Fig. 1). Two come from the elongation of the distance $D_{A}$ by a factor of $\sim (1+z)$ due to Universe expansion. It is assumed that such elongation dilutes the luminosity by $D_{A}^2 (1+z)^2$ according to the inverse square law. Another factor comes from the time dilation due to Universe expansion that reduces the photon emission/reception rate by $\sim (1+z)^{-1}$. The last factor comes from the cosmological wavelength redshifting that decrease the energy of photons by $\sim (1+z)^{-1}$. Therefore, a relevant relation is established in the standard cosmology between the angular diameter distance and the luminosity distance as

$$D_{L} = D_{A}(1+z)^2$$

(10)

2.2 Cosmic Microwave Background

According to the standard cosmology (Peebles (1993), Weinberg et al. (2008)), about 300.000 years after the Big Bang, the Universe was formed by a soup of protons, electrons and photons. When the temperature of the Universe fell down about 3000K, electrons were linked to protons to form hydrogen atoms. At this moment the decoupling was produced and the Universe became transparent to radiation since the scattering between free electrons and photons dropped drastically. At this epoch radiation and matter were in thermal equilibrium and the released radiation formed a perfect black body. The Cosmic Microwave Radiation detected nowadays has the same black body feature and thus it is assumed to be the relic of this radiation cooled and redshifted due to the effect of expansion.

A key question to support this theory is whether the black body spectrum shape can be maintained uniquely by the effect of the expansion or it is required some thermalization process. Let $N \nu \nu'$ be the number of photons emitted at decoupling at temperature $T$ with photon frequency between $\nu$ and $\nu + d\nu$ given by

$$N \nu \nu' = \frac{8 \pi V}{c^3} \frac{\nu^2}{e^{\frac{h \nu}{k T}} - 1} d\nu$$

(11)

and let $N' \nu' \nu'$ be the number of photons measured today at temperature $T'$ with photon frequency between $\nu'$ and $\nu' + d\nu'$ given by

$$N' \nu' \nu' = \frac{8 \pi V'}{c^3} \frac{\nu'^2}{e^{\frac{h \nu'}{k T'}} - 1} d\nu'$$

(12)

Dividing Eq. 11 by Eq. 12 and substituting the relationships $V' / V = (1 + z)^3$, $\nu' = (1 + z) \nu$, $d\nu = (1 + z) d\nu'$ and $T = (1 + z) T'$, all $(1+z)$ factors are cancelled out obtaining

$$N \nu \nu' = N' \nu' \nu'$$

(13)

Thus, the number of photons emitted at decoupling at temperature $T$ with photon frequencies between $\nu$ and $\nu + d\nu$, corresponds to the number of photons measured today at temperature $T'$ with photon frequencies between $\nu'$ and $\nu' + d\nu'$. Thus, it is plausible the CMB to be the relic of the Universe black body radiation at early states.

2.3 CMB luminosity-angular distance relationship within the Standard Model

The Standard Model also performs predictions in the relation between the angular diameter distance and luminosity distance based on CMB considerations. Thus, according to the Stefan-Boltzmann law, let $E$ be the CMB bolometric energy emitted per unit time per unit surface

$$E = \sigma T_{em}^4$$

(14)

where sigma is the Stefan-Boltzmann constant and $T_{em}$ the blackbody temperature at emission. The luminosity from a region of radius $R$ is

$$L = 4\pi R^2 \sigma T_{em}^4$$

(15)

Let $f$ be the received CMB flux corresponding to the solid angle $\theta^2$ subtended by the same region

$$f = \theta^2 \sigma T_{obs}^4$$

(16)

where $\theta$ can also be expressed by

$$\theta = \frac{R}{D_{A}}$$

(17)

On the other hand, due to the Universe expansion the relation between the temperature at observation and emission is

$$T_{obs} = \frac{T_{em}}{1 + z}$$

(18)

Substituting Eq. 15 and Eq. 16 in Eq. 7 and making use
2.4 Universe models

The link between observables as luminosity distance and redshift on one hand, and theory models from the other, are established by Eq. 3. As reference, Fig. 2 shows the plots for two cosmological models within the standard cosmology for a flat Universe: fiducial $\Lambda$CDM and Einstein-de Sitter ($\Omega_M = 1$) models.

3 COSMIC LENSING: A NEW PARADIGM

3.1 Cosmic Lensing: An unready effect of expanding Universe

The main support for an expanding Universe comes from the observed redshift of extragalactic sources. The wavelength of light is stretched out by the Universe expansion while traveling from galaxies to the earth, displacing the wavelength to the red. While much attention has been paid to the effect on the light produced by the expansion in the radial direction driving to the concept of cosmological redshift, a fundamental property on the transversal direction remains unnoticed. Let one to unveil this feature.

To preserve the cosmological principle in an expanding Universe, it is required that the effect of the expansion on the travelling light be homogeneous and isotropic both, on the radial and the transversal directions. Note that consequently the scale factor $a(t)$ of FLRW metric—responsible of the Universe expansion—affects to both the radial and transversal directions (Eq. 1). The application of the scale factor to the coming light in the radial axis drives to different known observational effects: the redshift of photons, the stretching of the radial distance by a factor $\sim (1 + z)$ and the time dilation of events. With respect to the transversal direction, the angular diameter distance ($D_A$) is properly defined as the ratio between the size of the source and the angle subtended by the source. Based on our common life experience and physical laws on non-expanding environments, one can assume that the subtended angle of a receding source is reduced by a factor $\sim (1 + z)^{-1}$ when the distance to the source grows by the same factor. In fact that is what occurs with the angle subtended by the source, but not in the image of the source. According to the isotropic expansion, the cone of the subtended image scales with the expansion both on radial and transversal directions. That is, any image coming from a cosmological object is lensed (i.e. increases its apparent size by a factor of $\sim (1 + z)$) while simultaneously is receding (and therefore reducing its apparent size by a factor $\sim (1 + z)^{-1}$). Combining the receding and lensing contributions due to expansion the overall cosmological effect is the angular size conservation of sources images while travelling to earth. That is, in spite of the Universe expansion, we see the images of the objects as they were (same angular size) when the light was emitted.

Nevertheless, the consequences of this fact on the luminosity distance has not been regarded to date. The angular size conservation of the image while Universe expands, produces the flux focusing, that affects deeply to the luminosity. The image flux focusing towards the observer (in spite of the elongation on the distance travelled by the image due to expansion) produces a considerable increment on the flux received from the source with respect to the expected by the Standard Model. Thus, the received flux by the observer is the same that would receive in a non-expanding Universe but dimmed only by the time dilation and wavelength redshifting due to expansion, but not by the elongation of distance (Fig. 3). Let one to explain in detail both effects: the known effect of image

Figure 2. Luminosity distance for $\Lambda$CDM and Einstein-de Sitter ($\Omega_M = 1$) models in the standard cosmology.

Figure 3. Flux focusing (Cosmic Lensing): Simplified 2D view of the flux focusing effect on a flat universe. The augmented distance travelled by light rays due to expansion does not affect to the flux received since the rays are always focused to the observer. Only the time dilation and wavelength redshifting decrease the flux.

of Eq. 17 and Eq. 18, Eq. 10 is again recovered. Therefore, it seems to be an apparent agreement between the relationship $D_L/D_A$ described in Section 2.1 and that derived from CMB considerations.
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Figure 4. Schematic representation of distances for a flat universe in the Standard Model (left) and Cosmic Lensing (right). The inner circumference represents the source at emission while the outer (left/right) represents the (source/apparent source image) at reception. Note that transverse comoving distance ($D_M$) and angular diameter distance ($D_A$) coincide in both models, nevertheless the luminosity distances ($D_L$) differ. In the Standard Model it is assumed that the flux is diluted by the distance elongation due to Universe expansion increasing $D_L$ by a factor $(1+z)$. On the contrary, the right figure corresponding to the source image shows that the flux is not diluted since the directions of the light rays remain unaltered pointing always to the observer. Only the effect of time dilation and wavelength redshift contribute to flux diminution globally as a factor of $(1+z)^{-2}$ yielding the relation $D_L = (1+z)D_A$.

Angular size conservation and the unnoticed effect of geometrical flux preservation or flux focusing.

A simplified 2D view of the image angular size conservation is drawn in Fig. 4 (right) for a flat Universe. Let one consider the lateral view of the plane containing the source and the observer $O$ at a distance $D_A$. Let $OAB$ be the triangle formed by the observer and the two extremes of the object in the considered plane. As long as the Universe expands, the triangle $OAB$—which enclose the image light rays from the source to the observer—preserves its form while scales into the triangle $OA'B'$ due to expansion. That is, the angular size of the image is preserved while travelling to the earth independently of the rate of expansion of the Universe. Moreover, the angles of the rays from the image to the observer remain unaltered while traveling to earth in spite of the Universe expansion. This fact ensures the geometrical flux preservation beyond the flux dimming due to time dilation and wavelength redshift, and leaving apart any other effects as scattering or absorption.

Taking into account the flux preservation, the flux received from a cosmological source is $\sim (1+z)^2$ times larger than the expected by the Standard Model, while the luminosity distance is smaller by a factor of $\sim (1+z)^{-1}$. Thus, the luminosity distance $D_L$ defined within the Cosmic Lensing paradigm is

$$D_L = D_M = D_A(1+z)$$

and the flux equation becomes

$$f = \frac{L}{4\pi D_A^2(1+z)^2}$$

Figure 5. Cosmic lensing: Effect of the expanding Universe on the images of an extended source (flat Universe). The image of the source remains focused towards the observer all along the time it is travelling to the earth.

At this point one can ask what is wrong with the inverse-square law represented by Fig. 1 for the Standard Model. The first thing one should note is that Fig. 1 considers light rays departing from a point source. In this situation the source transversal image information is missing in spite it is also affected by the expansion. While it has not impact in static environments as shown the Gauss’s theorem, the situation changes in an expanding Universe. The effect of working with extended sources in an expanding Universe can be clarified by changing the point of view from the source to the observer. Fig. 5 shows how the apparent image becomes focused to the observer regardless the redshift and hence independently of the expansion rate. This focusing of the image flux towards the observer deactivate any luminosity dilution with distance.
expansion beyond $\sim 1/D_A^2$ due to the source-target length at emission time. The redshift dependence of Eq. 20 comes exclusively from time dilation and wavelength redshifting.

3.2 Cosmic Lensing: the new luminosity-angular distance relationship deduced from CMB equations

The new luminosity-angular distance relationship can also be derived from CMB. Due to the expansion of the Universe, the differential surface elements at different epochs are related by

$$dS' = (1 + z)^2 dS$$ \hspace{1cm} (21)

Let one rewrite Eq. 14 to have a common surface unit at observation and at emission

$$E' = \sigma T_{em}^4 dS' = \sigma T_{em}^4 \frac{dS}{(1 + z)^2}$$ \hspace{1cm} (22)

The bolometric luminosity becomes then

$$L' = \frac{\sigma T_{em}^4 4\pi R^2}{(1 + z)^2}$$ \hspace{1cm} (23)

Substituting Eq. 16 and the new bolometric luminosity given by Eq. 23 in Eq. 7 we obtain

$$D_L^2 = \frac{\sigma T_{em}^4 4\pi R^2}{4\pi \sigma T_{obs}^4 \theta^2 (1 + z)^2}$$ \hspace{1cm} (24)

Making use of Eq. 18 and simplifying we obtain

$$D_L^2 = \frac{4\pi R^2 (1 + z)^4 T_{obs}}{4\pi \theta^2 (1 + z)^2 T_{obs}} = \frac{(1 + z)^2 R^2}{\theta^2}$$ \hspace{1cm} (25)

Introducing the value of $\theta$ given by Eq. 17 we have

$$D_L^2 = \frac{(1 + z)^2 R^2}{R_A^2} = D_A^2 (1 + z)^2$$ \hspace{1cm} (26)

and then

$$D_L = D_A (1 + z)$$ \hspace{1cm} (27)

Thus, we obtain again Eq. 19 previously formulated by geometrical considerations.

3.3 Cosmic lensing effect on cosmological models

Cosmic Lensing states that a Universe expanding according to FLRW metric should meet the luminous-angular distance relation given by Eq. 27. Note that $D_L$ is lower by a factor of $(1 + z)^{-1}$ with respect to the predicted by the Standard Model. Fig. 6 shows how Cosmic Lensing paradigm changes the luminosity distance-redshift relationship with respect to the standard cosmology for the two cosmologies considered in Section 2. Theories based on luminosity measurements must integrate the new paradigm. Moreover, the Standard Model and its current predictions within the $\Lambda$CDM cosmology have to be revised. The Hubble constant, the dark matter and dark energy content of the Universe must also be re-evaluated within the new paradigm.

4 CONCLUSIONS

The Standard Model compile the current knowledge of the Universe based on Einstein equations and FLRW metric, along with the definition of basic cosmological distances. At the end of the last century an unexpected announcement appeared related to the acceleration of the Universe expansion as a result of the study of Type Ia supernovae within the Standard Model. Since the acceleration expansion announcement, large amount of data have been collected through several extragalactic surveys that apparently confirm the acceleration of the Universe expansion according to the Standard Model.

In this paper the Cosmic Lensing paradigm is presented. Cosmic Lensing unveil an unready characteristic of extragalactic images in an expanding Universe: the flux focusing. The flux focusing produces an amplification on the received flux from extragalactic sources by a factor of $\sim (1 + z)^2$ with respect to what is expected by the Standard Model. As a consequence, the ratio between luminosity distance and angular diameter distance is redefined to $(1 + z)$.

Cosmic Lensing affects deeply to the equations used to determine the cosmological parameters (Hubble constant, dark matter density, dark energy densities, etc.) and hence to the Universe evolution. A re-evaluation of data within the new paradigm is required.

A careful analysis of data from current surveys as SDSS (Alam et al. (2015)), DES (Flaugher (2005)), PAU (Benitez et al. (2009)), JPAS (Benitez et al. (2014)), or the future more powerful experiments as DESI (Flaugher & Bebek (2014)), Euclid (Laureijs et al. (2010)) or LSST (Ivezic et al. (2008)) promises to provide the necessary precision to determine the evolution and fate of the Universe within the new paradigm.
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