Will LCDM cosmology survive the James Webb Space Telescope?

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Abstract

The James Webb space telescope (JWST) is about to deliver scientific data. Fundamental contributions are expected in all fields of astronomy. Here we focus on the distant Universe, for the JWST is expected to consolidate once and for all the Lambda Cold Dark Matter (LCDM) cosmology. Most crucially, "The End of the Dark Ages: First Light and Reionization" and "The Assembly of Galaxies" are the first two of the four primary JWST Science Goals. Here we critically challenge the general expectations, giving a set of alternatives, presented before they can be either proved or disproved. Our conclusion is that the JWST will provide data incompatible with LCDM cosmology, forcing a revolution both in astronomy and fundamental physics.

Keywords: Cosmology: general

1 Introduction

The James Webb space telescope (JWST), with a 6m primary mirror, infrared optimized, and placed at the Lagrange point 2 at about 1.5 million km from earth, is expected to revolutionize our understanding of the Universe. Important contributions are expected in all fields of astronomy[1], though in this paper we will limit ourselves to

[1]A long list of white papers on JWST expectations can be found here https://www.stsci.edu/jwst/about-jwst/history/white-papers; see also [33].

discussing expectations for the high z Universe. According to the JWST science cases (e.g., [12]), data obtained with this telescope are expected to confirm the modern view of the Universe, as exemplified by the Big-Bang theory and the lambda cold dark matter (LCDM) paradigm, which has the merit of explaining the two most important observations about the distant Universe: the redshift of the light coming from distant sources, and the cosmic microwave background (CMB). The cost to achieve this, however, is huge.

In short, beside the basic concept of a beginning of the Universe and expansion of space, this vision of the Universe requires three additional basic ingredients: inflation (an initial period of tantalizing rapid expansion that made space flat and the cosmic microwave background isothermal), dark matter (required among other to form structure fast enough to fit in the available time frame) and dark energy (to explain accelerated expansion). The reality of expansion, inflation, dark matter, and dark energy is now taken for granted. However, a critical analysis shows that only circumstantial evidence exist for them (e.g., [9]).

It is precisely the task of the JWST, and the main reason for building it, to test this global view of the Universe and the predictions of LCDM cosmology for the yet unexplored Universe at $z > 10$.

2 Expectations for JWST in LCDM cosmology

The properties of the Universe are thought to be well understood up to $z \sim 8$ when it was ~ 600 Myr old. At larger distance a huge amount of work have been dedicated to characterize the cosmic microwave background (CMB), at $z \sim 1100$, allowing the determination of the cosmic parameters down to unprecedented accuracy (e.g., [30]). Between these two epochs, population III stars, globular clusters, supermassive black hole seeds, and the first galaxies are expected to have formed (e.g., see [5] for a review). Galaxies are thought to assemble through hierarchical merging of building blocks with smaller mass. The first such building blocks, with $M \simeq 10^4 M_\odot$ form in these models at $z \gtrsim 15$ (e.g., [6]; [8]).

Here is a typical description of what JWST is expected to do, extracted from [11]: *One of the key science goals for JWST is to discover the first galaxies to exist in the distant universe. [...] Deep imaging with NIRCam will allow the discovery of star-forming galaxies out to possibly* $z \sim 20$ *(and certainly to* $z \sim 15$*). In addition to probing the physics of galaxy formation only* ~ 200 *Myr after the Big Bang, such studies will allow us to trace the evolution of the cosmic star-formation rate density to the earliest cosmic times, search for evidence of the first stars (via enrichment signatures, or possibly supernovae), and provide extremely tight constraints on the contribution of galaxies to reionization (both through tracking the evolving galaxy population back to earlier times, and also by probing deeper at the currently studied epoch corresponding to redshifts* $6 < z < 10$*). These topics are at the forefront of current astrophysical research, being prominently featured in the recent US decadal survey as well as NASAs Cosmic Origins goals. Most crucially,"The End of the Dark Ages: First Light and Reionization" and "The Assembly of Galaxies" are the first two of the four primary JWST Science Goals.*

Will the JWST confirm this scenario?

3 Interpreting data differently

In an attempt to answer this question, we show here that a different interpretation of the available data is possible, as long as the concept of expansion of space is abandoned. We "assume" an Euclidean static universe, with redshift due to some physical process other than expansion, further retaining at all z the Hubble law $d = cz/H_0$, well-assessed in the local Universe.

In this framework, the bolometric luminosity L and the flux F from a source are related by the relation $F = L/[4\pi d^2(1+z)]$, where the factor $(1+z)$ takes into account energy losses due to the redshift. When using flux per unit frequency, that is AB magnitudes, this relation further simplifies to $F = L/(4\pi d^2)$. The choice of a linear relation for the distance is motivated by the fact that the derived flux-luminosity relation is (numerically) remarkably similar to the one found in the LCDM concordance cosmology (Fig. 1). Actually, it might be seen that, over the years, the various preferred cosmologies have been approaching the Euclidean+redshift one discussed here (Fig. 2).

We stress this point because it might appear surprising. As long as *luminosity* and derived quantities like luminous mass are concerned, LCDM results are equivalent to what is found in a static universe with redshift (up to at least $z = 5$).

Under Euclidean geometry the true size R and the apparent size r of a distant object are linked by the standard relation $r = R/d$, where r is in radians. At large z, the Euclidean distance keeps increasing, rapidly becoming vastly larger then the LCDM angular size distance D_A, which is famous for decreasing after $z \sim 1.5$. In first approximation one can write $D_A \sim d/(1+z)^{1.5}$ (fig. 3). This allows us to make the important prediction that when the *linearsize* of distant non-evolving objects is concerned – dimension, surface, or volume and derived quantities like density – a strong evolution with z will be observed when data are interpreted in LCDM.

It should be noted that this cosmological model is neither a non-evolving universe, nor the Einstein-De Sitter static Universe often used in literature. We stress that our aim here is not to propose a new cosmology. Rather, it is to point out some general expectations derived from what is known locally, expectations that clash with LCDM predictions. If needed, when referring to LCDM, we adopt the standard parameters: H_0= 70 km s^{-1} Mpc, $\Omega_M = 0.3$, and $\Omega_\lambda = 0.7$. None of our claims depend on the exact value of these parameters.

4 What JWST will not find

Here is a short list of what the JWST is expected to find, reinterpreted in our adopted framework.

4.1 The size and build up of galaxies

It is a matter of fact that the apparent size of distant objects keep decreasing as their distance increases, as obviously expected for an Euclidean static universe. In the LCDM framework, this implies that distant galaxies are intrinsically smaller than their

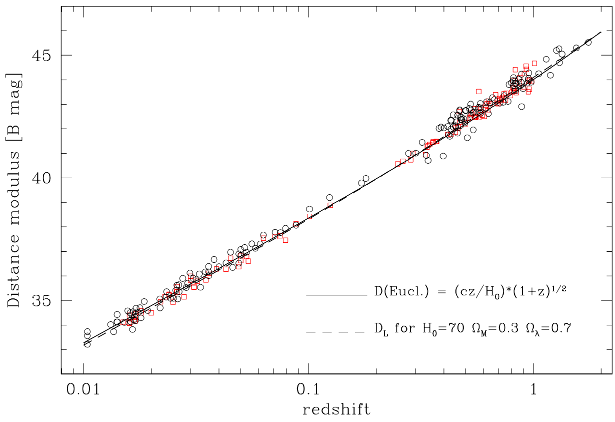

Fig. 1 Hubble diagram for type Ia supernovae compared to LCDM (dashed line) and Euclidean (solid line) predictions. Over this limited range of z the two curves mostly overlap. Data from [3] (red squares) and the gold sample from [25] (circles).

local counterparts (e.g. [7]; [34]; [36]). This progressive size reduction is consistent with the idea that we are witnessing the build up of galaxies in the young universe.

When comparing galaxies of *similar* UV luminosity, the size is parameterized to evolve as $(1+z)^{\alpha}$, with α found in the range $-0.75 < \alpha < -1.4$ according to the sample under consideration and the redshift range probed, and large uncertainties (e.g., [35]; [32]; [28]; [2]; [29]). Whatever the correct $alpha$ might be, it is suspicious that when considering other quantities that do not require the adoption of a cosmology to be evaluated, e.g. the Sersic index, velocity dispersion, etc., no evolution is found ([29] and references there in).

We put forward here that the observed size evolution is *entirely* due to the adopted cosmology. Indeed, available data are fully consistent with $\alpha = -1.5$, as expected if the Euclidean framework is correct (fig. 4, see section 3). In other words, far from probing evolution, these data are showing that galaxies of similar luminosity have similar size at all redshifts.

Strictly related to galaxy sizes is the issue of surface brightness, which should suffer a dramatic dimming $\propto (1+z)^{-3}$ in any expanding universe, dimming that is not observed. In LCDM this is consistently justified by the computed small size of galaxies, thus the inferred intrinsic surface brightness is increasingly higher, offsetting the cosmological dimming.

In the Euclidean static framework the rest frame UV surface brightness is expected to remain constant, as confirmed to be the case up to $z = 5$ ([17]; [16]).

In the static framework, distant galaxies are computed to be as large and luminous as the local one, suggesting nothing special is happening at these redshifts. We thus predict the JWST, far from probing the formation of the first galaxies, will demonstrate the existence of fully formed massive galaxies comparable to local galaxies at $z > 10$. Specifically, for resolved galaxies of a given mass, the angular radius will be found to decrease as $\theta \propto 1/z$.

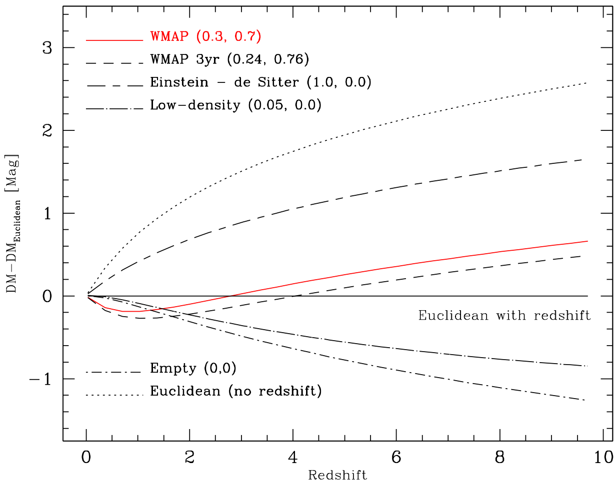

Fig. 2 Distance modulus difference with respect to the Euclidean static plus redshift relation. The various cosmologies that over time had been proposed as the correct one did increasingly approach the Euclidean plus redshift relation. The most modern, the LCDM consensus cosmology, remain within few tenths of a magnitude up to $z \sim 5$. The JWST should probe region where the two distances are significantly different.

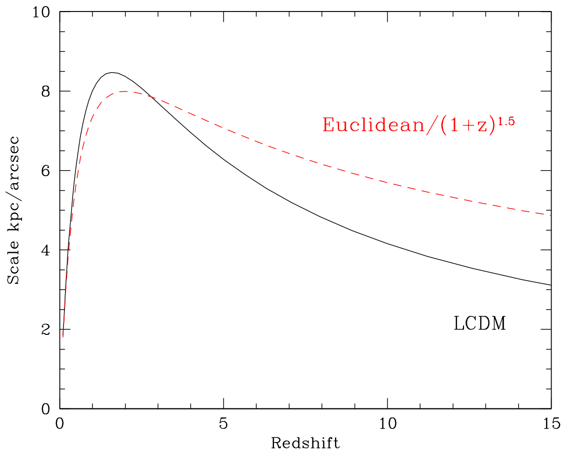

Fig. 3 Scale factor in kpc per arcsec versus redshift, as predicted by LCDM cosmology (solid line), compared to the Euclidean values divided by $(1 + z)^{1.5}$ (red dashed line). This is not an attempt to fit the LCDM curve which cannot be parameterized as a simple function of (1+z). Rather, this is meant to show that when galaxies are investigated within LCDM, a size evolution approximately proportional to this factor is expected.

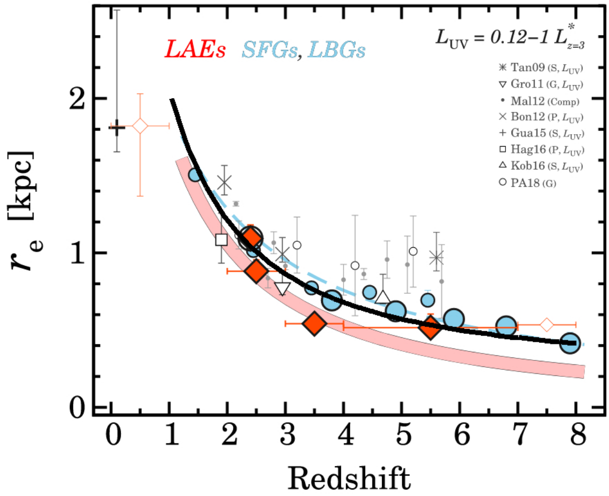

Fig. 4 Size evolution of distant L^* galaxies of fixed UV luminosity, in LCDM cosmology. Note the very small estimated effectire radius. This is figure 9 of [29], showing the state of the art on this subject, on top of which we have plotted the $(1+z)^{-1.5}$ trend (black line) expected if there is no size evolution and the Euclidean static scenario is correct.

4.2 Dynamical mass and negative dark matter

The estimated small size of distant galaxies in LCDM has many important consequences. One of the most striking is that the dynamical mass can be smaller than the luminous mass, which is physically impossible. Indeed, for either disk or elliptical galaxies, the gravitational mass including all matter (visible and dark), within a given radius r, can be calculated from V^2r or σ^2r. This dynamical mass, can then be compared to the stellar mass calculated from the spectral energy distribution and luminosity. As shown above, the luminosity computed in LCDM and the static case is the same so there are no problems here. However, if the physical radius r is underestimated for an expanding universe model, then the calculated dynamical mass can be less than the observed stellar mass. Such "negative dark matter" galaxies have already been observed with HST (e.g., [24]) and we predict that the physically impossible deficit of gravitational mass will continue to worsen with increasing z. On the other hand, such contradictions will not appear if the physical radius is calculated on the non-expanding case.

4.3 Galaxy rotation curve

In typical, large spiral galaxies in the local universe, velocity rotation curves have a characteristic shape. They increase linearly in the central-most region, then turn over and begin to decline with increasing radius R to become approximately flat, with v independent of R. Observations have shown that the radius at which the flattening starts in a given galaxy is related to the velocity at that R by the relation $v^2/r = a_0$, where a_0 is a constant with value $a_0 = 1.2 \times 10^{-8}$ cm s^{-2} ([4]; [13]). In other words, the circular acceleration observed at this radius is a constant, which defines the acceleration regime below which the mass discrepancy is found and dark matter appears ([21]).

This provides a tool to directly test the distance-size relationship, since v^2/R can be derived for any galaxy with a sufficiently spatially resolved rotation curve, something that the JWST will certainly provide.

This exercise can be done already for the $z = 4.2$ galaxy SPT0418-47 ([27]). This is a strongly-lensed galaxy and the rotation curve is computed by deprojecting the lensed image, so has some degree of uncertainty. Nevertheless, the rotation curve is found to have the typical shape observed in local galaxies. The flattening, is estimated to start at an angular radius of 0.22 arcsecond where the rotation velocity is $\sim$ 280 km/s ([27]).

In the LCDM framework this angular radius is calculated to yield a linear radius of 1.5 kpc (fig. 5). Assuming this value of R the acceleration V^2/r is 1.7×10^{-7} cm/s^2, an order of magnitude greater than the local value of a_0. Note that the whole galaxy is estimated to be so small in LCDM that no matter the value of R used, the acceleration is always several times larger than a_0. Of course, distant galaxies don't have to behave like local ones, so this might not be a problem. However, in the case of an Euclidean non-expanding model, this angular radius yields a linear radius of 19 kpc, and $V^2/r = 1.4 \times 10^{-8}$ cm/s^2, in complete agreement with the local value.

A similar test can be made placing SPT0418-47 on the baryonic Tully-Fisher relation ([19]). For an asymptotic velocity of 260 km/s a mass of $\sim 2 \times 10^{11}$ M$_\odot$ is derived, consistent with the estimated size of the galaxy and its infrared luminosity 2.4×10^{12} L$_\odot$ ([27]; taking into account that luminosity is the same in the two cosmologies). For this value of the mass, the flattening of the rotation curve is predicted to occur at $\sim$ 15 kpc, in agreement with the shape of the rotation curve (Fig. 5). By contrast, the dynamical mass computed by [27] is about an order of magnitude smaller (because in LCDM the radius is small, see previous section).

It is important to add that SPT0418-47 closely resembles local disk galaxies in having a very high ratio of rotational velocity to random velocity ([27]), which is not at all what is expected from a model of hierarchical assembly.

Thus, in the Euclidean static scenario this galaxy does appear to be rather normal, a true Milky Way analog at $z = 4.2$. Similar considerations can be made for ALESS 073.1, another disk galaxy at z=4.755, finding the same results ([15]). Whether this is correct or a coincidence will soon be known, since the JWST will provide exquisite rotation curves of galaxies at much larger z than available today, providing a sharp test for any cosmological model.

4.4 Super massive Black holes

Supermassive black holes (SMBH) with M> 10^9M$_\odot$ are routinely reported to exist at redshift as large as $z \sim 7$ (e.g., [37]), when the Universe was a mere $\sim$ 700 Myr old.

How SMBH can form in such a short period of time is difficult to explain. Here is another extract from the JWST science case: "... *the first stars were 30 to 300 times as massive as the Sun and millions of times as bright, burning for only a few*

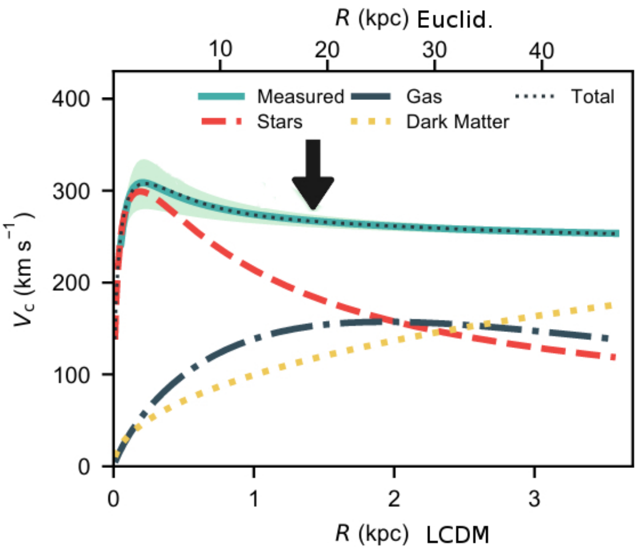

Fig. 5 The rotation curve of the galaxy SPT0418-47 at $z = 4.2$ (green curve), as reported by [27], with the typical description in terms of stars, gas, and dark matter. Note the very small computed size of the galaxy in LCDM (lower scale), compared to the Euclidean model (upper scale). The flattening of the rotation curve at large radii is evident. The arrow show the radius where the curve flattens out, according to [27]. When quantities are evaluated in the Euclidean framework, at this position the acceleration v^2/r is consistent with a_0.

million years before meeting a violent end. Each one produced either a core-collapse supernova (type II) or a black hole. [...] The black holes started to swallow gas and other stars to become mini-quasars, growing and merging to become the huge black holes now found at the centers of nearly all massive galaxies. The supernovae and the mini-quasars should be observable by the JWST." Note the use of the expression "mini-quasar" to refer to quasar with BH of intermediate mass, say $10^4 - 10^5$ $M_\odot$, which supposedly had time to form.

We challenge these claims, taking the existence of SMBH at high z as indicative that the Universe is much older than generally claimed. Thus we foresee that JWST will not discover mini-quasars. On the contrary, fully fledged quasars will be observed all the way to the largest z the JWST will probe. These quasars will be found to have BH masses (estimated for instance from the properties of their broad line regions) similar to the ones observed at lower z, worsening the formation problem. Furthermore, if the well known BH-bulge mass relation observed in local galaxies ([14]) holds also at these redshifts, then the existence of massive galaxies will be inferred, strengthening the claims made in previous sections.

Cosmologists will have to decide the maximum redshift beyond which it became physically impossible to build SMBHs, and if quasars are found beyond this limit, acknowledge that the age of the Universe is severely sub-estimated by LCDM models.

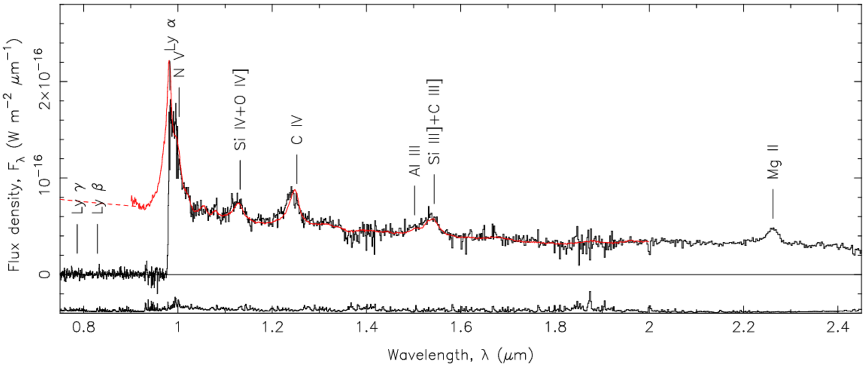

Fig. 6 Spectra of one of the most distant QSO known, ULAS J1120+0641 (black line) at z=7.09, compared to a composite spectrum derived from lower-redshift quasars (red line, Telfer02). The similarity is striking suggesting no significant chemical evolution occurred during this period of time. Figure adapted from Fig. 1 of Mortlock11.

4.5 Elliptical galaxies

According to the hierarchical model for structure formation elliptical galaxies, the most massive stellar systems in the local Universe, are the last galaxies to form. It is typically claimed that ellipticals went through a burst of star formation at $z \sim 5$, and then increased in size by merging with late–type galaxies of comparable mass (e.g., [23]; [10]), a bottom-up formation scenario naturally expected in cold dark matter dominated cosmologies (e.g., [31]). In the local Universe ellipticals do nevertheless appear to form an homogeneous family, with a number of indicators like the black hole - bulge mass relation, color gradient, and well behaved mass distributions (i.e., the de Vaucouleurs law), that contrast with the idea that they might be the result of the haphazard assembly of small pieces. Rather, this data is better fit with the idea of a monolithic collapse with a single intense burst of star formation at high redshift ($z \gtrsim 10$). Whatever the case, the JWST, being optimized for the IR, is ideally suited to detect distant elliptical galaxies (if they exists). Sticking to our Euclidean model we see no reasons for elliptical galaxies not to exist at high z, so we foresee that JWST data will result in their discovery.

4.6 Chemical evolution of quasars

Quasars spectra are self-similar at all redshifts, suggesting that their physical and chemical evolution is minimal (e.g., [22]). In particular, heavy elements are observed even in the most distant ones (Fig. 6). Spectra of distant quasars hence impose stringent constraints on the time scales for generation III stars to form, evolve, explode as supernovae spreading the heavy elements, which in turn have to find their way to a black hole and finally show up as emission lines in the QSO spectra. Whether this is possible to occur within the time scale imposed by LCDM cosmology is difficult to determine at the moment.However, we predict that JWST will push this trend further out in redshift ,exacerbating the problem.

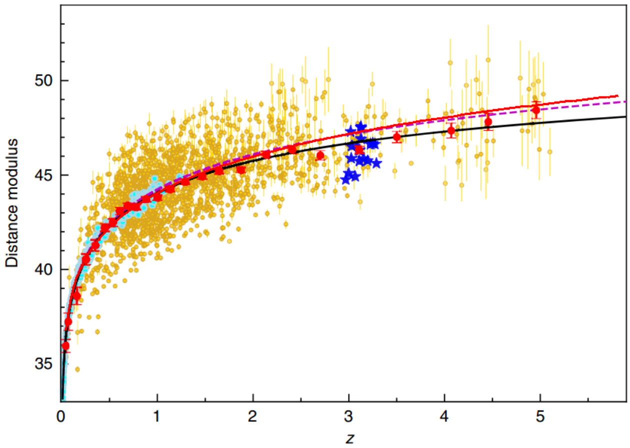

Fig. 7 The Hubble diagram for supernovae type Ia (cyan points) and a large sample of quasars (yellow points and blue stars). The red points show the calibrated distance modulus in bin of increasing redshift for the QSO, with their best fit (Black line). The upper red line is the Euclidean prediction, while the dashed purple line gives the LCDM one. Figure adapted from [26].

5 Conclusion

We have presented a short list of specific cases – others could have been included, though we believe we made our point clear – in which data probing the distant Universe have been interpreted differently from what is usually done. This alternative interpretation rests on the assumption that space is static Euclidean and the linear Hubble law is valid to arbitrarily large redshifts. In this framework, distant galaxies are found to be similar to local galaxies, indicating nothing special is happening at the largest probed z. Quasars suggest the same. All this shows that there are few indications that observations are actually approaching the beginning of the Universe.

Notably, our reinterpretation is based on the extrapolation of what is known to be valid locally, with zero free parameters, in sharp contrast with the continuously increasing number of unproved assumptions necessary to keep LCDM alive. Using quasars, a nice extension up to $z = 5$ of the supernovae distance modulus plot ([26]) shows how serious this is (Fig. 7). The Euclidean plus redshift plus linear Hubble law scenario scores equally well (or equally bad if you prefer) as the LCDM, without requiring a plethora of hypothesis including a dark sector representing 96% of the whole Universe.

Our main conclusion is that the JWST will fail to probe a pre-stellar Dark Age, which, if it exists at all, lies extremely far in the past. Hopefully, this will force the development of a new vision of the Universe, which of course doesn't necessarily have to be the one put forward here, forcing a revolution in astronomy and fundamental physics. A number of indicators suggest this revolution is already happening. It is indeed well demonstrated that the dynamical properties of galaxies in the local Universe do show systematic features – the most striking possibly being the mass Discrepancy - acceleration relation ([18]) – whihc are better explained by modifying gravity than invoking dark matter, as proposed in the modified Newtonian dynamics

(MOND, [21]; [20]). At present, however, disposing of dark matter and expansion of the universe is unthinkable, for the whole LCDM paradigm would fall apart. A new set of observations is necessary to give the final push. If the JWST will provide it as we are suggesting here, a serious discussion of the basic concept of the expansion of the Universe and the nature of the CMB will start (a discussion that is now impossible). In physics, a new explanation for the redshift will have to be found, the whole concept of a dark sector abandoned, and gravity in the low acceleration regime rewritten.

The Ptolemaic geocentric cosmology did not survive the introduction of the telescope by Galileo Galiei. Will LCDM survive JWST?

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