The raw data, figures, references and charts that support all findings and results of the article titled the thermodynamics of dark energy, expansion of the universe and expanding space-time

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Hubble law

In 1929 ,,Edwin Hubble showed images that the redish shift far distance galaxies along
With their distance constantly is increasing. It caused Hubble published an article in that year in which a relation called Hubble law was mentioned . Discovery of Hubble was related to determination of coefficient of statement (distance) indicating not being zero.as we know, redism is defined as follows:

$$z = \frac{\lambda - \lambda_0}{\lambda_0} = \frac{\Delta\lambda}{\lambda_0} \qquad (1)$$

(Note that is an object close to us $\Delta\lambda$ be negative, we called this mood bluism) If the wavelength change is defined as a Doppler transition then the speed of being far away of observed galaxy is :

$$v = c(\frac{\Delta\lambda}{\lambda_0})=(cz) \qquad (2)$$

Where C is light velocity. Using galaxy appearance to measure its distance, Hubble discovered the following relation :

$$CZ=Hd \qquad (3)$$

where H is Hubble constant. Comparing the first and second equations, another form of Hubble rule is gotten.

$$V=Hd \qquad (4)$$

where d is the distance of a galaxy, H is Hubble constant which indeed it is not a real constant and V is the velocity of being far away because of the universe expansion. Now we can describe Hubble rule as follows: a rule in astrophysics and cosmology which suppose the world is expanding at a constant speed for all the time.

Till the discovery of Hubble basically ,all philosophical ideas related to the universe dynamic mood was not so that they imaged it constant. i.e. neither expansion nor contraction is involved in this idea. Indeed, to save the relativity theory of Einstein in 1916 the cosmology constant was added to it. ($ref.$[1]).

Following Hubble's law and by comparing two galaxies with different distances from the same origin and as a result the speed of moving away from the same origin, the following relationships describe the comparison of the distance and the speed of their escape from the origin :($ref.$[2]).

$$\frac{v_1}{v_2} = \frac{d_1}{d_2} \tag{5}$$

(a) **(b)**

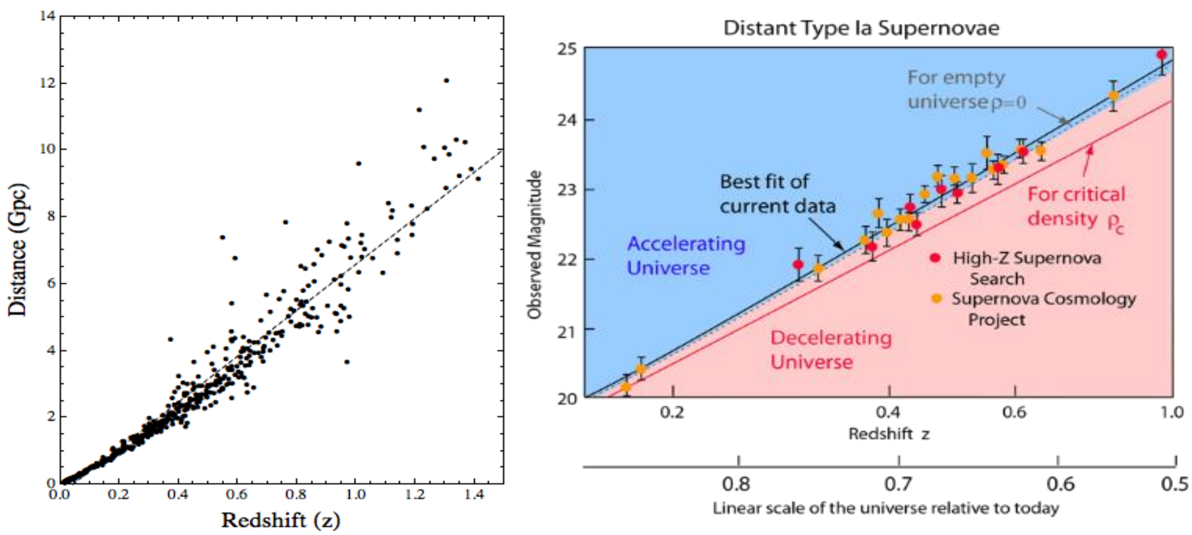

Fig.1|Hubble's law can be easily depicted in a "**Hubble diagram**", in which the velocity (assumed approximately proportional to the **redshift**) of an object is plotted with respect to its **distance** from the observer **(a)** ($ref.$[3]). The diagram illustrates how the accelerate of expansion of the universe would be positive, nagative or even zero based on the density of mass-energy distributed in universe (**b**).

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Fig.2|Space-time Metric Distance Changes between galaxies in **Hubble deep background (HFD)** .One of the most fundamental findings was the discovery of large numbers of galaxies with high redshift values. ($ref.^4$).

I emphasize that the simple relation of the Hubble equation (V = Hd) only applies to near galaxies with the small Z. For z values greater than 0.8, the cosmological effects are important for redshift to distance. For a flat world, the correct relation is:

$$\boldsymbol{d} = \frac{CZ(1+\frac{Z}{2})}{H(1+Z)^2} = \frac{V+\frac{VZ}{2}}{H+HZ^2} \Rightarrow\!\!> \boldsymbol{d} = \frac{V(2+Z)}{2H(1+Z^2)} \qquad (6)$$

It is noteworthy that Hubble rule has different forms. The Hubble equation, despite its simplicity, has many applications in astrophysics and cosmology. Another form of these is Hubble Time, which is used in cosmic physics to calculate the life of some objects, such as spherical clusters, stars, and so on. Such explanations of the Hubble Principle will be ignored because they do not need to be described in this article. ($ref.$[4]).

Expansion of the universe

Studying supernovae Ia provides a far-reaching evidence of accelerated expansion of the universe. The magnitude of the supernova's brightness is an indicator of that galaxy's distance, while its redshift indicates how fast the galaxy is moving away from Earth. The galaxies with the highest amount of redshift would seem to be far from where our universe would have been growing at a steady acceleration.($ref.$[5]).

The expanding universe is not expanding into another environment; it is expanding space-time itself and carrying galactic clusters. As space expands, time will also move away.

All parts of the universe expand at a constant speed. So the farther apart the two clusters are, the faster the space between them expands.

The universe expansion does not mean that all galaxies are alienated from each other, but that this alienation is only visible on a very large scale. Within smaller universe structures, components may be approaching each other, such as our Milky Way galaxy, which is approaching the neighboring Andromeda galaxy, and is expected to collide for another 4 billion years. It is not true, of course, to say that everything in the universe is expanding. The Earth is not getting bigger; the solar system and the Milky Way is too. Even the size of the galaxy clusters does not grow larger because gravity holds them together. Only at high distances between galactic clusters does the expansion of space overwhelm the gravitational absorption spectrum. .($ref.$[6]).

The phenomenon of redshift in galaxies is the main seal of confirmation of the expansion of the universe. Redshift is defined as a function of the wavelengths of emitted and observed electromagnetic radiation. This phenomenon is duplicated in the sense that the spectral lines received by a galaxy moving away from us are moving towards longer and redder wavelengths. (Transition phenomenon to red). The greater the redshift, the faster the speed of departure will be. The farther away the galaxies, the faster they will go .($ref.$[7]). Now, if we want to say one complete sentence about the expansion of the universe**, the universe expansion is an increase in the metric distance between the objects of the universe over time**. It is an internal expansion, which means that it returns to the relative distance between the components of the universe and does not mean moving objects to outer space.

Albert Einstein allowed physicists to provide solutions to describe an expanding universe by solving nonlinear Einstein equations.

Trying to find such a description led to the emergence of the metric of Burton-Walker that was obtained by solving Einstein's field equations. If the most reasonable assumptions of homogeneity and a process

(Homogeneity implies that beyond a length scale a sample volume is slightly different from other volumes), then the problem is contained.

These two assumptions are a necessary and sufficient condition for using the Robertson-Walker metric to describe the following equation.

$$(ds^2=C^2dt^2-R^2(t)\times[dr^2/(1-kr^2)+r^2(d\theta^2+\sin^2\theta d\phi^2) \qquad (7)$$

In this equation ،θ و ϕ, r are the equi- coordinates. A tested particle in the expanding universe remains the same coordinates. Expansion (or contraction of anything else) is described by the function R (t), known as the scale structure. The constant k defines the topology of space-time curvature as follows:

K {
- Spherical closed
- Critical planner
- Open ground

We now simplify the Einstein field equations by placing the Robertson-Walker metric and the ideal energy-momentum gas form in the above equation. It can then be concluded that the time equation is as follows:

$$T_{00} \Rightarrow \frac{8\pi G\rho\,(t)}{c^2} = (3k/R_0^2)(R_0/R)^2 + (3/C^2)\left(\frac{R^0}{R}\right)^2 - \Lambda \qquad (8)$$

Space-time components lead to:

$$\frac{T_{ii}\, 8\pi G\rho\,(t)}{c^4} = -\left(\frac{k}{{R_0}^2}\right)\left(\frac{R_0}{R}\right) - (2/c^2)\left(\frac{R}{R_0}\right) - \left(\frac{1}{c^2}\right)\left(\frac{R_0}{R}^2\right) + \Lambda \qquad (9)$$

Solving this equation using the first rule of thermodynamics, the equation of motion, mass stability, and a form of Newton's second rule (R ̈/ R = (- 4πGP) / (3C ^ 2)) eventually lead to the construction of such an equation. .($ref.^{8}$).

In 1922, physicist Alexander Friedman obtained the first expansion equations of the homogeneous and isolated universe in terms of the scale factor and its first and second order derivatives over time using the Robertson-Walker metric.

Friedman's two independent spatial and temporal equations are:

Space Independent $\frac{\dot{a}^2+kc^2}{a^2} = \frac{8\pi GP+\Lambda c^2}{3}$ **(10)**

Time independent $(\frac{\ddot{a}}{a} = -\frac{3\pi G}{3}\left(P + \frac{3P}{c^2}\right) + \frac{\Lambda c^2}{3})$ **(11)**

Where $H = \frac{\dot{a}}{a}$ is called the Hubble principle, G is the Newtonian gravitational constant, 1 the cosmological constant, and C is the speed of light. In the past, at the time of expansion, all galaxies gathered together. We call this event (the Big Bang). .Note that the Big Bang took place at a certain time, not in one particular place, because in the Big Bang all parts of the world were close together. Since then, the world has expanded. Of course, not in the empty space; the space expands as it passes. Galaxies can easily act as signs of this expansion. Therefore, the redshifts of galaxies, commonly called Doppler transmissions, are not really so.

They are caused by the different distances of our universe signs, the galaxies are in world history at different times. Expansion does not imply that we are in the center of the universe if expansion is uniform, then another observer in the galaxy is the Hubble law (a law in astrophysics and cosmology that assumes that the universe is constant at a constant speed for all time). Is expanding) will see. Finally it must be recognized that H (Hubble constant) is not really a constant. It has to change due to the gravitational effects of galaxies. H generally decreases with the age of the universe. .($ref.^{9}$).

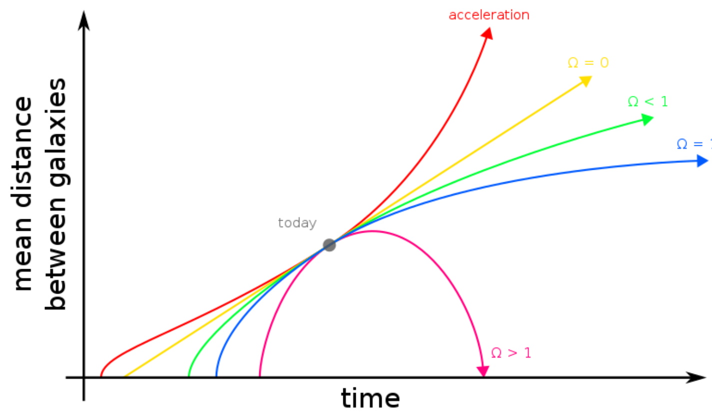

Fig.3| The age and ultimate fate of the universe can be determined by measuring the Hubble constant today and extrapolating with the observed value of the deceleration parameter, uniquely characterized by values of density parameters (Ω_M for matter and Ω_Λ for dark energy). A "closed universe" with $\mathbf{\Omega_M > 1}$ and $\mathbf{\Omega_\Lambda = 0}$ comes to an end in a Big Crunch and is considerably younger than its Hubble age. An "open universe" with $\mathbf{\Omega_M \leq 1}$ and $\mathbf{\Omega_\Lambda = 0}$ expands forever and has an age that is closer to its Hubble age. For the accelerating universe with nonzero Ω_Λ that we inhabit, the age of the universe is coincidentally very close to the Hubble age.

The information presented here for the expansion of the universe, most of which were collected in the 1920s and 1930s, shows that the galaxies are moving away from each other as the universe expands. Therefore, this expansion has been proven experimentally and in fact, the scientific community has accepted it since its introduction. .(*ref.*[10]).

As we know, the expansion of the universe is accelerated (according to the latest measurements, the acceleration of the expansion of the universe is equal to 73 km/ MPc.S). Observational data about the redshift pattern of galaxy clusters show that the redshift rate of the clusters increases with a positive acceleration. This means that the expansion rate of the universe will lead to speeds higher than the speed of light in the future, which is confusing for newcomers and sometimes professional physicists. But speeds greater than C in the expansion of the universe do not contradict special relativity. One of the long-term effects of the expanding universe is that over the next 3 trillion years most galaxies will disappear from our view at a speed faster than the speed of light. .(*ref.*[11]).

Now one can feel the need for an energy source that acts in the direction of accelerated expansion of the universe and against gravity; a special type of energy that directly inflates the space-time fabric at an accelerating rate. Ever since the need for an energy distinct from other fundamental energies in nature has been raised, the effort to understand the nature and essence of this energy has begun, and the scientific community has called it dark energy.

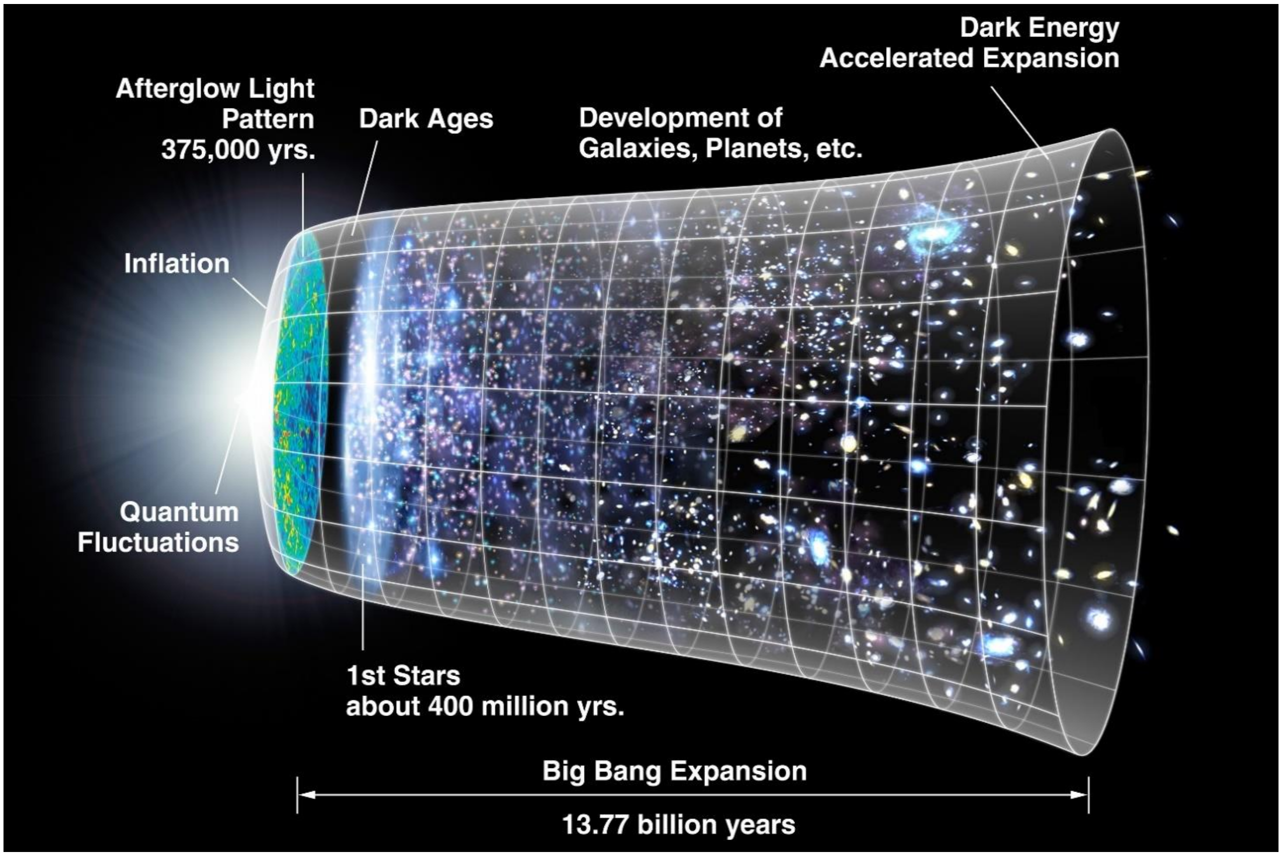

Fig.4| A graphical representation of the expansion of the universe from the big bang to present day. This visualization indicates that expansion created, and continues to create all of known space and time.

Dark Energy

In physical cosmology, dark energy is a form of energy that affects the space-time on the largest scale internally. Since its discovery, dark energy has become one of the central problems in theoretical physics and cosmology. The first observational evidence for its existence came from measurements of supernovas, which showed that the universe does not expand at a constant rate; rather, the universe's expansion is accelerating ($ref.^{12}$). Understanding the universe's evolution requires knowledge of its starting conditions and composition. Before these observations, scientists thought that all forms of matter and energy in the universe would only cause the expansion to slow down over time. Measurements of the cosmic microwave background (CMB) suggest the universe began in a hot Big Bang, from which general relativity explains its evolution and the subsequent large-scale motion. Without introducing a new form of energy, there was no way to explain how scientists could measure an accelerating universe. Since the 1990s, dark energy has been the most accepted premise to account for the accelerated expansion. As of 2021, there are active areas of cosmology research to understand the fundamental nature of dark energy. ($ref.$[13])

Assuming that the lambda-CDM model of cosmology is correct ,($ref.$[14]) as of 2013, the best current measurements indicate that dark energy contributes 68% of the total energy in the present-day observable universe. The mass–energy of dark matter and ordinary (baryonic) matter contributes 26% and 5%, respectively, and other components such as neutrinos and photons contribute a very small amount. ($ref.$[15−16]). Dark energy's density is very low (~7×10^{-30} g/cm^3), much less than the density of ordinary matter or dark matter within galaxies. However, it dominates the universe's mass-energy content because it is uniform across space. ($ref.$[17]).

Two proposed forms of dark energy are the cosmological constant ($ref.$[18]) (representing a constant energy density filling space homogeneously) and scalar fields like quintessence or moduli (dynamic quantities having energy densities that vary in time and space) .Contributions from scalar fields that are constant in space are usually also included in the cosmological constant. The cosmological constant can be formulated to be equivalent to the zero-point radiation of space, i.e., the vacuum energy($ref.$[19]). However, scalar fields that change in space can be difficult to distinguish from a cosmological constant because the change may be prolonged.

Due to the toy model nature of concordance cosmology, some experts believe ($ref.$[20])that a more accurate general relativistic treatment of the structures on all scales ($ref.$[21]) in the real universe may do away with the need to invoke dark energy. Inhomogeneous cosmologies, which attempt to account for the back-reaction of structure formation on the metric, generally do not acknowledge any dark energy contribution to the universe's energy density.

The evidence for dark energy is indirect but comes from three independent sources:

- Distance measurements and their relation to redshift, which suggest the universe has expanded more in the latter half of its life. ($ref.$[22]).

- The theoretical need for a type of additional energy that is not matter or dark matter to form the observationally flat universe (absence of any detectable global curvature).
- Measures of large-scale wave patterns of mass density in the universe.

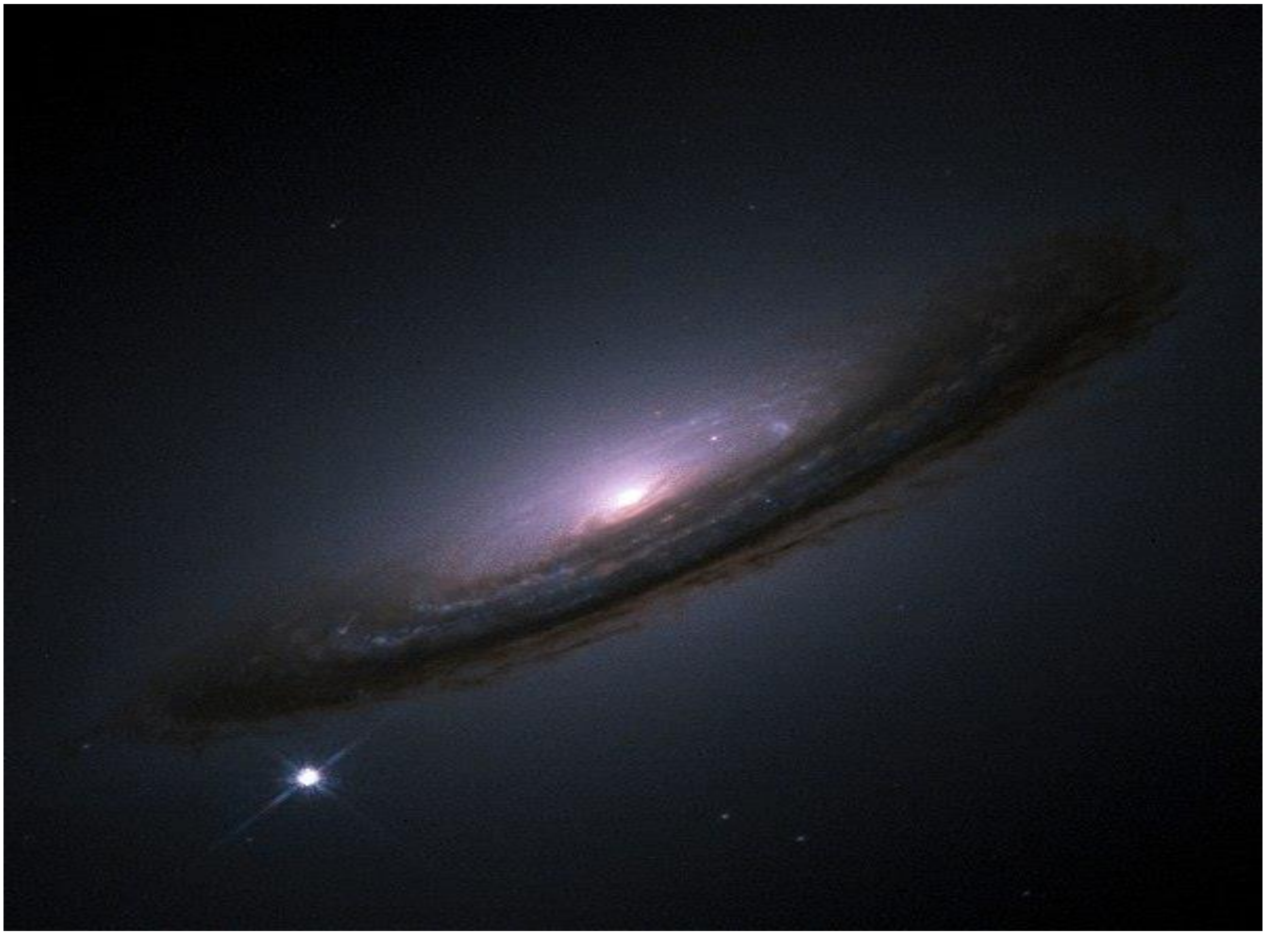

Fig.5| A Type Ia supernova (bright spot on the bottom-left) near a galaxy.

In 1998, the High-Z Supernova Search Team($ref.^{23}$) published observations of Type Ia ("one-A") supernovae. In 1999, the Supernova Cosmology Project ($ref.^{24}$). followed by suggesting that the expansion of the universe is accelerating.

These observations have been corroborated by several independent sources. Measurements of the cosmic microwave background, gravitational lensing, and the large-scale structure of the cosmos, as well as improved measurements of supernovae, have been consistent with the Lambda-CDM model. ($ref.^{25}$). Some people argue that the only indications for the existence of dark energy are observations of distance measurements and their associated redshifts. Cosmic microwave background anisotropies and baryon acoustic oscillations serve only to demonstrate that distances to a given redshift are larger than would be expected from a "dusty" Friedmann–Lemaître universe and the local measured Hubble constant. ($ref.^{26}$).

Supernovae are useful for cosmology because they are excellent standard candles across cosmological distances. They allow researchers to measure the expansion history of the universe by looking at the relationship between the distance to an object and its redshift, which gives how fast it is receding from us. The relationship is roughly linear, according to Hubble's law. It is relatively easy to measure redshift, but finding the distance to an object is more difficult. Usually, astronomers use standard candles: objects for which the intrinsic brightness, or absolute magnitude, is known. This allows the object's distance to be measured from its actual observed brightness, or apparent magnitude. Type Ia supernovae are the best-known standard candles across cosmological distances because of their extreme and consistent luminosity.

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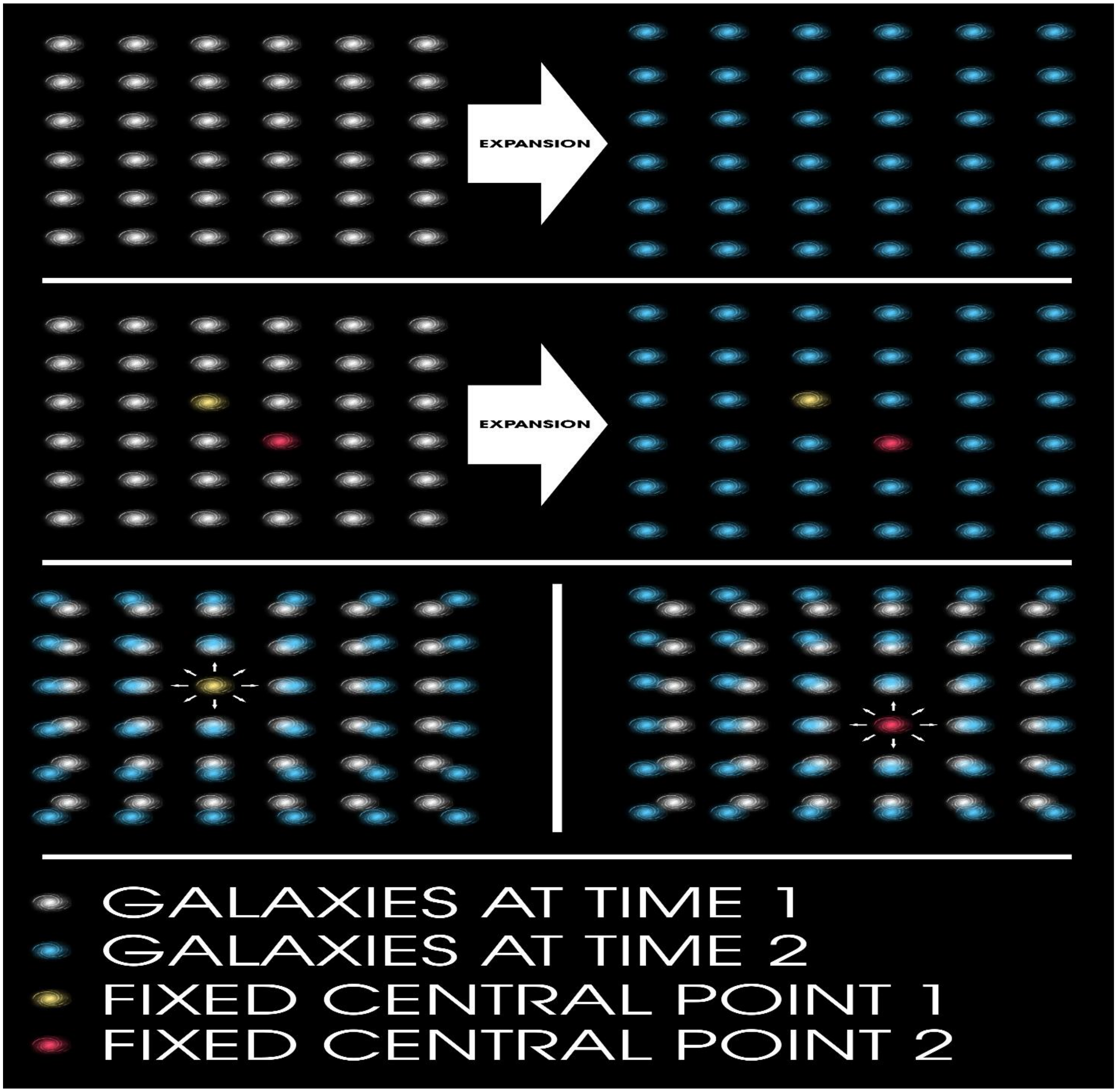
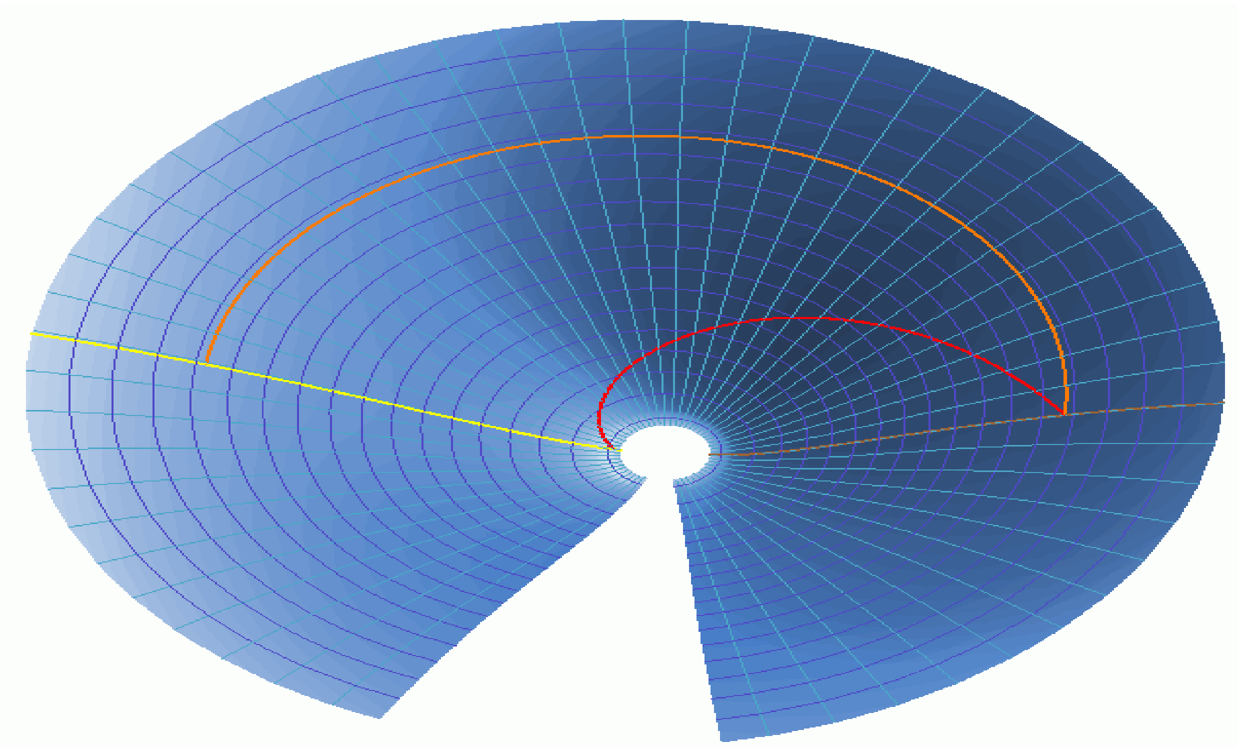
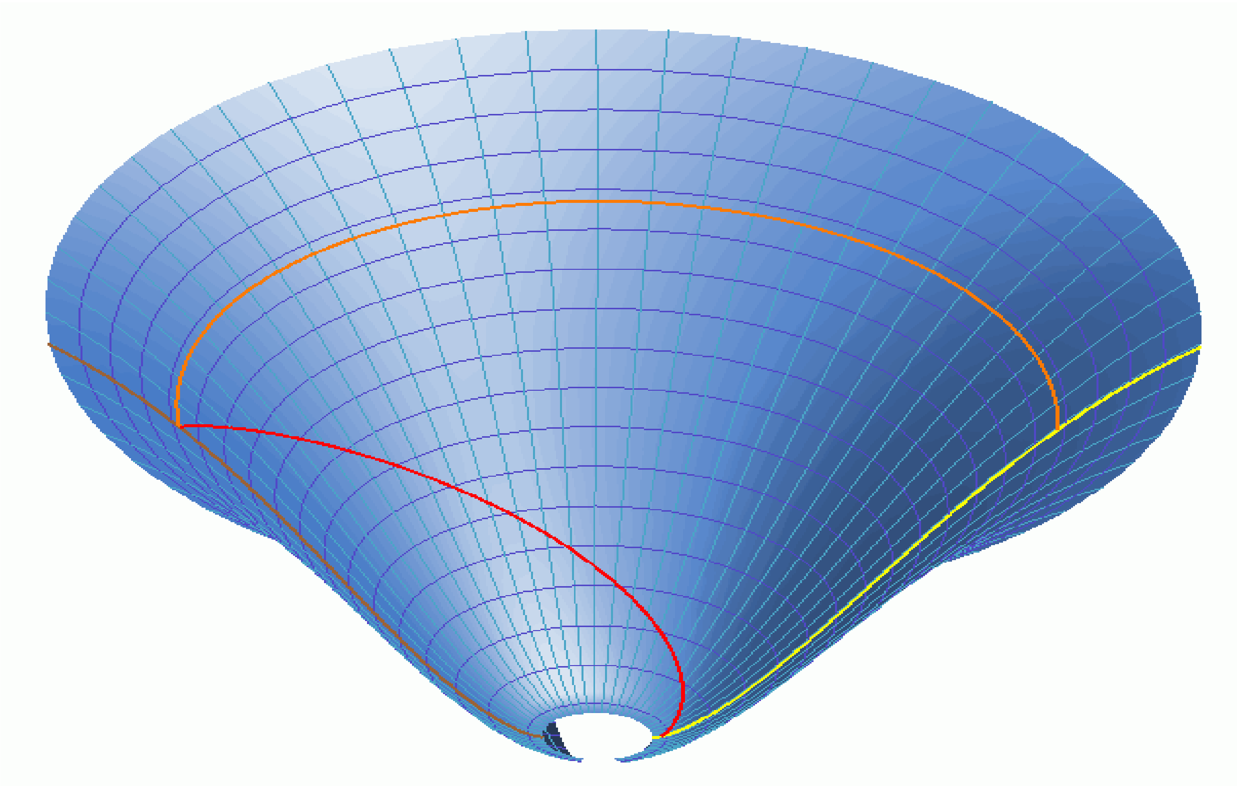


Extended Fig.1| The diagram depicts the expansion of the universe and the relative observer phenomenon. The blue galaxies have expanded further apart than the white galaxies. When choosing an arbitrary reference point such as the gold galaxy or the red galaxy, the increased distance to other galaxies the further away they are appear the same. This phenomenon of expansion indicates two factors: there is no centralized point in the universe, and that the Milky Way Galaxy is not the center of the universe. The appearance of centrality is due to an observer bias that is equivalent no matter what location an observer sits.





Extended Fig.2| Two views of an isometric embedding of part of the visible universe over most of its history, showing how a light ray (red line) can travel an effective distance of 28 billion light years (orange line) in just 13 billion years of cosmological time. (Mathematical details)

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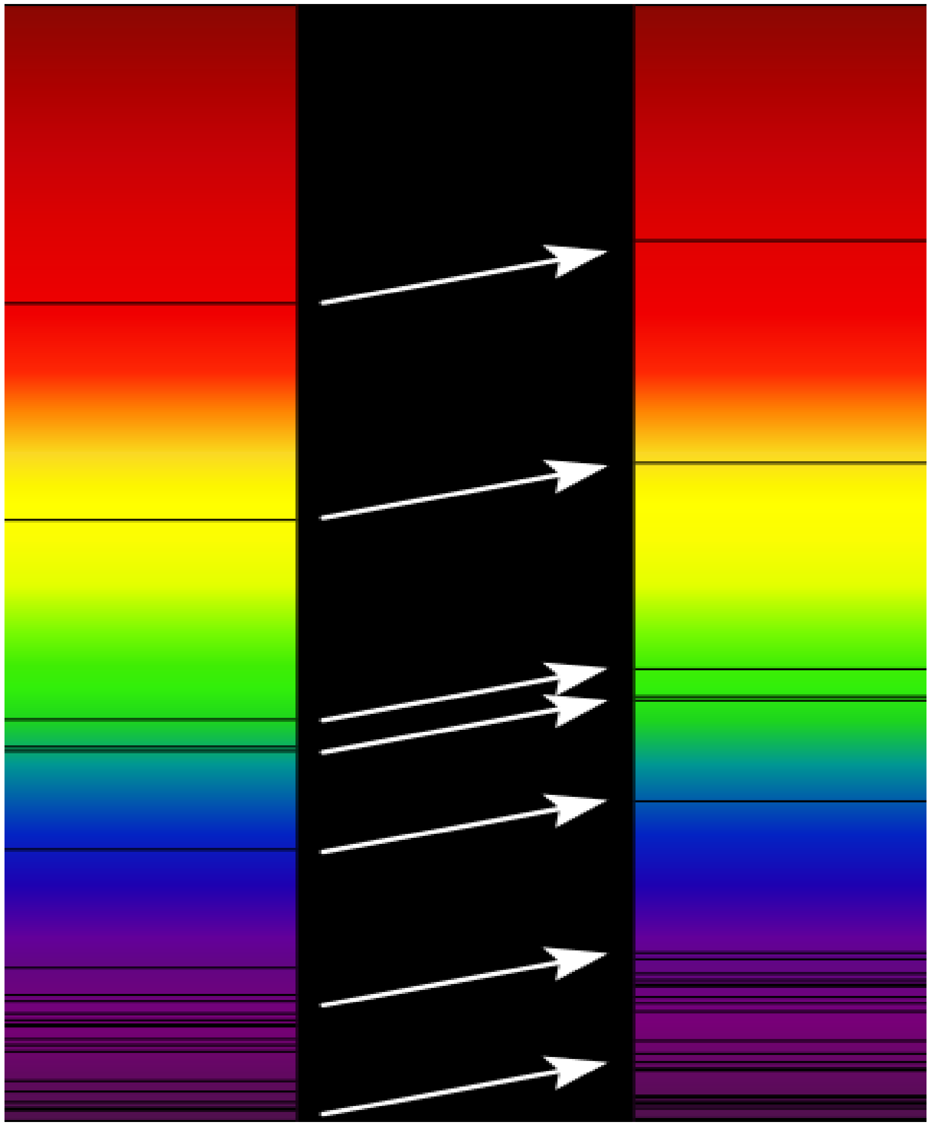
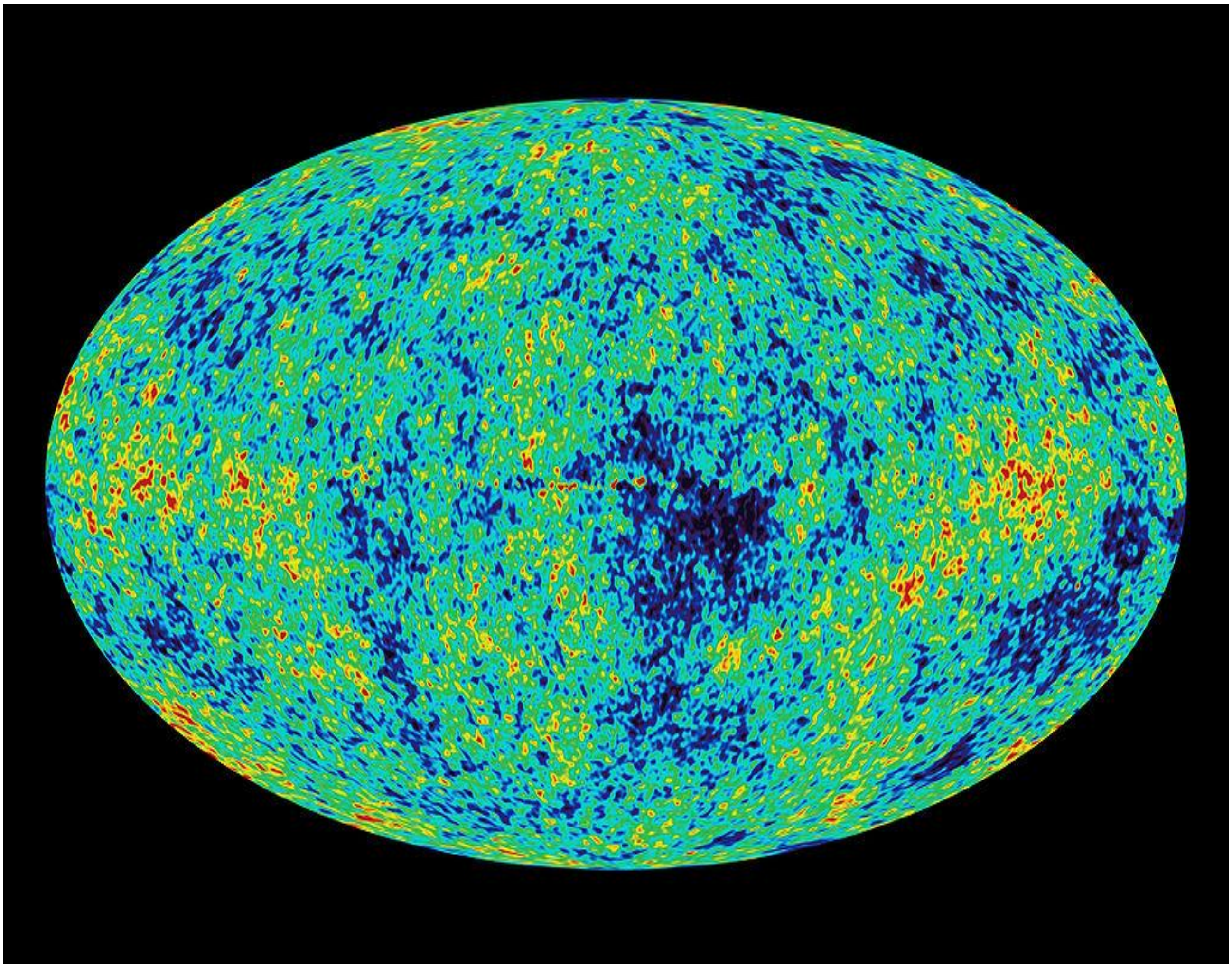


Extended Fig.3|Absorption lines in the visible spectrum of a supercluster of distant galaxies (right), as compared to absorption lines in the visible spectrum of the Sun (left). Arrows indicate redshift. Wavelength increases up towards the red and beyond (frequency decreases).



Extended Fig.4|All-sky mollweide map of the CMB, created from 9 years of WMAP data. Tiny residual variations are visible, but they show a very specific pattern consistent with a hot gas that is mostly uniformly distributed.

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