A New Theory on Redshift of Photons

Xiaoping Hu
Boly Inc.
3235 Kifer Rd., Suite 260, Santa Clara, CA 95051.

Fifth Revision on Oct. 8th, 2019.

Abstract

This article presents a new theory on redshift of light from celestial bodies. Lately it has been found that the Hubble constant calculated from different methods discord so much that calls arise for new physics to explain. Also, in addition to many unsolved puzzles like dark matter and source of expansion force, we shall show in this article that the current theory of redshift implies a few hidden, unreasonale assumptions. By assuming photon has temperature and its thermal energy is fully converted to wave energy, this article shows that photon can have a new redshift called Temperature Redshift, which not only is more significant for remote stars or galaxies, but also better fits the observational data, including those used in Hubble constant calculation. As such, if true, this new theory not only adds to our new understanding of photons, but may totally change our current understanding of the Universe, i.e., the Big Bang theory.

Key Words: Temperature, Photon, Spectrum Line, Redshift, Doppler Redshift, Hubble's Law, Universe Expansion, Cosmologic Redshift, Big Bang Theory.

1. Introduction

Redshift ([10]-12]) of Spectrum Line ([1]-[3]) has been used as a primary measurement in modern astrophysics and cosmology ([4]-[9]). Our basic understanding of the Universe hinges on our correct interpretation of the redshift data. To this date, three kinds of redshifts have been proposed ([4]): relativistic Doppler Redshift, Cosmologic Redshift, and Gravitational Redshift, though the Cosmologic Redshift and relativistic Doppler Redshift are the most often used. The gravitational Redshift, if any, is too small to have any significance in most areas. The Cosmologic Redshift ([24][25]) depends on a few hidden, and very unreasonable assumptions as we shall reexamine in this article. In any way, the existing theories have now lead to discord on the measurement of the Hubble constant ([18][20][22][29]), which is a fundamental parameter in astrophysics and cosmology. As such, there arises the need for a better understanding of the redshift ([18]). Worse, in addition to a few contradictions that have been found but unconvincingly justified in the academics, this article shall show that: (1) a new redshift, called Temerapture Redshift, justifies the data very well without unreasonable assumptions; (2) if Temperature Redshift is the major source of the redshift data observed, then, a static Universe model may result.

With the aim of providing a better understanding of the redshift data observed and resolving many of the paradoxes and puzzles, a new theory on redshift of light from celestial bodies is proposed. The new theory is based on the assumption that photon has temperature which reduces when photon travels through the Universe. The reduction of photon's temperature also leads to a new kind redshift, called Temperature Redshift in this article. It turns out that the Temperature

Redshift can be so much larger that all other three previously studied redshifts mentioned above can all be ignored in practice. The consistency of this theory with Hubble's Law and observational data used in Hubble constant computation is also examined. The result shows that the new theory fits historical data and Hubble's Law amazingly well, but without the absurd implications that would arise when the observed redshift values are primarily attributed to Cosmologic Redshift or relativistic Doppler Redshift. Surprsingly Hubble's Law looks like a special case of the newly established law. The Temperature Redshift actually shows that photons indeed can get tired when their temperatures cool down (they will rest in peace when the temperature reaches absolute 0).

2. The relativistic Doppler Redshift

One of the major Redshift that has been used in astrophysics, astronomy and cosmology (e.g., to calculate distance of stars) is the Doppler Redshift. Now we shall show, attributing the redshifts observed from celestial bodies to Doppler Redshift alone would lead to almost absurd results.

When the star is moving at high speed in line of sight (0 degree with line of sight) away from the observer, the following relativity Eq. would result ([4])

$$1+Z_d = 1 + (f_{emit} - f_{obsvr}) / f_{obsvr}) = \frac{\sqrt{1+v/c}}{\sqrt{1-v/c}} \quad (1)$$

where f_{emit} is the frequency of the light from a emitting star, f_{obsvr} the frequency we observed on Earth, Z_d the Doppler Redshift of frequency, v the speed of star relative to observer, and c the light speed. Here we use subscript d to distinguish Doppler Redshift with Temperature Redshift to be discussed later.

Now, the highest Z_d value scientists have recorded is 1809 ([4]). Now, if this redshift is from Doppler Redshift alone, then solving v/c from Eq. (1) with Z_d = 1809, we would get

$$v/c = ((1+Z_d)^2 - 1) / ((1+Z_d)^2 + 1) \quad (2)$$

$$= ((1+1809)^2 - 1) / ((1+1809)^2 + 1) = 0.99999939$$

That means, the speed of the star would be so close to the light speed that it would exceed the precision limit of our best measurement tools today! Even with the smallest Z_d value 5.2 scientists have observed[4], we would also get the speed of the star relative to light as

$$v/c = ((1+5.2)^2 - 1) / ((1+5.2)^2 + 1) = 905.44 / 907.44 = 0.997796$$

How come the stars that scientists have tracked all have a speed so close to light and yet they are not smeared into clouds? This is unthinkable because they are enormously massive stars.

Similarly, when a star is moving perpendicular to the line of sight, then the following relativity equation would result[4]:

$$1 + Z_d = 1 / \sqrt{1-v^2/c^2} \quad (3)$$

Solving v/c from the above Eq., we get

$$v/c = \sqrt{1-1/(1+Z_d)^2} \quad (4)$$

Now, if we replace Z_d by 1809 in Eq. (4), we'd get v/c = 0.99999984, and if we replace Z_d by

5.2, we'd get v/c = 0.9869907. Again the the speed of the stars are still very close to light speed.

These speed numbers definitely conflict with majority speed measurements of the stars in our own Galaxy. As such, in the past, the a different kind of redshift, Cosmologic Redshift, is regarded the main redshift source, which will be examined in the next section together with Hubble's Law.

3. The hidden assumptions in Hubble's Law and Cosmologic Redshifts

The Hubble's law states

$$v = H_0 D \tag{5}$$

where v is the speed of the measured star, H_0 the Hubble constant, and D the distance of the star to the observer. However, this law is obtained under the assumption that

$$v = cZ_d \tag{6}$$

where c is the speed of light, and Z_d the Doppler Redshift. This assumption holds only for small Z_d << 1, while the measurements of most spectrum line shift of stars have $Z_d > 5$. When v is large, the relation between v and Z_d is described in Eq. (2) and (4), or the more generic equation as in Eq. (24) in a later section. We must note most measurements of the velocities of stars come from Doppler's Effect.

The original data used in Hubble's Law actually says

$$Z_d = (H_0 / c)\, D \equiv k_D\, D \tag{7}$$

where k_D is used here to denote a linear relationship of redshift with distance, as in the original and follow-on observational data used to calculate the Hubble Constant.

Fig. 1. shows a data fitting for Hubble's Law ([25]):

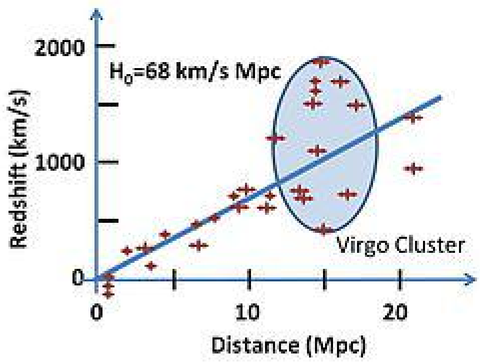

Fig 1. Sample Data fitting of Hubble's Law

We must note that the original and follow-on data fitting as exampled in Fig. 1 shows only that the redshift is proportional to the distance as expressed in Eq. (7). In addition, the fitting has issues when distance is large as can be seen in Fig. 1. However, in later on researches, Eq. (5) has been used extensively and the assumption and validity condition of Eq. (6) are both forgot. For example, if redshift $Z_d = 5$, then according to Eq. (6), v would be equal to 5c, violating the the special relativity principle. In later discussions of this article, we shall see, extending Eq. (7) into Eq. (5) is a wrong step.

We shall call Eq. (5) as the ***postulated*** Hubble's Law (which will be shown incorrect shortly), while Eq. (7) as the ***observational*** Hubble's Law. So far, Eq. (7) is regarded as an observed fact, but has not been derived from any theory.

Because Doppler Redshift is very small for low speed stars, modern cosmology ([30])

attributes the observed redshift as in Eq. (7) almost fully to Cosmologic Redshift, which is expressed as follows ([30]):

$$Z_C = a(t_{obsvr}) / a(t_{emit}) - 1 \tag{8}$$

where $a(t_{obsvr})$ is the Expansion Scale Factor of the Universe at observation time t_{obsvr} , $a(t_{emit})$ the Expansion Scale Factor of the Universe at emitting time t_{emit}, and Z_C the Cosmologic Redshift (caused by Universe expansion).

Tradionally, $a(t_{obsvr}) / a(t_{emit})$ has been approximated with the following linear function

$$a(t_{obsvr}) / a(t_{emit}) = 1 + (t_{obsvr} - t_{emit}) H_c \tag{9}$$

where H_c is the linear approximation term of $a(t_{obsvr}) / a(t_{emit})$. Then Eq. (8) becomes

$$Z_C = (t_{obsvr} - t_{emit}) H_c = (D / c) H_c = (H_c / c) D \tag{10}$$

where D is the distance between the observer and emitter, and c the light speed.

Due to the similarity of Eq. (10) and (7), the academic has been inclined to think that

$$Z_C = Zd, \quad H_c = H_0, \tag{11}$$

The observed redshift Z_d of remote stars can be mostly attributed to the cosmologic redshift Z_C.

There are several issues here. First of all, by assuming $Z_C = Z_d$, one has to assume that there is no other redshift, and the only meaningful redshift is Cosmologic Redshift. If we find another redshift that also fits the observation very well, then Cosmologic Redshift cannot be assumed the only cause of the observed redshift data. The second issue is with Expansion model of the Universe, where the energy comes from? By multiplying c on both sides of Eq. (10), we get

$$v = c Z_C = (t_{obsvr} - t_{emit}) * cH_c , \tag{12}$$

which suggests:

$$dv/dt = cH_c \tag{13}$$

where v is considered to be the receding speed of the light emitting stars. Eq. (13) suggests that receding stars all have a constant acceleration speed, and by Newton's second law, F = m * dv/dt, there must a force that constantly pushes each star.

Thirdly, the assumption that the Universe's expansion has an acceleration raises many questions: (1) What is the force that drives the expansion of the Universe? (2) Why is the expansion so uniform along different directions (even after billions years)? (3) Eq. (9) suggests $a(t_{obsvr}) / a(t_{emit})$ is either 1 (not expanding at all, with $H_c = 0$), or, $a(t_{obsvr}) / a(t_{emit})$ is increasing with time (expanding with acceleration). Now because F = m * dv/dt, how does the expansion driver (presumably God) know exactly how much force to exert on each of an almost infinite number of stars according to its mass so that each star has the same acceleration? (4) How is the force applied to each star, especially when planets have their own circular motion? These questions are there as long as $H_c \neq 0$;

We must note here, even without assuming $v = c Z_C$, by looking at Eq. (9), as long as H_c is none-zero, the above questions regarding to the Expansion Model of the Universe are still there and have to be answered.

Eq. (12) also suggests that, for longer enough time, the receding speed of the stars would be larger than the light speed. As section 2 shows, when v is close to c, $v = c Z_C$ does not hold any more. However, multiply both sides of Eq. (9) by any nonzero (initial) speed v_0, we can still conclude that for longer enough time, the expansion speed of the Universe would exceed the speed of light, contradicting the special relativity principle.

4. Temperature Redshift of Photon

For a material p with mass, when the temperature of it heats up, its thermal energy, usually denoted by C_pT (where C_p is the heat capacity coefficient of particle p and T the absolute temperature), would increase with temperature quite linearly, except at phase change points. Now, what about photon? Does photon have temperature? If so, does it have phase changes?

To this date, the question whether photon has temperature has never been asked. If all other particles of mass have temperatures, why would not photon? If photon has no temperature, that would mean temperature has no effect on it, and then if it is cooled to absolute zero degree, its wave will still vibrate, contradicting our understanding that at absolute 0 degree, everything rests. Therefore, in this article we shall assume photons do have temperatures. This assumption leads to meaningful results as shown below.

Since we know only one phase of photon, it is reasonable to assume that the thermal energy of a photon would also increase with the temperature linearly (like other particles of mass). Assume further the heat capacity coefficient of a photon is C_p, and the thermal energy of a photon is then given by C_pT.

Now, how would a photon hold its thermal energy? So far we all know that the energy of a photon is hf ([28]), where h is the Planck constant and f the frequency of photon. Since photon is massless and it has no other energy except wave energy, therefore it is reasonable to assume that the thermal energy obtained by photon will be directly converted to its wave energy. That would mean

$$hf = K_T\, C_pT + hf_0, \tag{14}$$

where K_T is a conversion coefficient from thermal energy to wave energy, f_0 the frequency at absolute zero degree.

Unless photon lost some thermal energy during conversion to wave energy, Kp has to be 1. f_0 is supposed to be zero, because no wave energy is possible at absolute zero degree. With these assumptions, Eq. (14) becomes

$$hf = C_pT \tag{15}$$

Eq. (15) is important in that it states that the frequency of a photon actually reflects its temperature.

Now, if Eq. (15) is true, then it would lead to Temperature Redshift when the temperature of a photon is cooled from temperature T_1 to T_2: the frequency difference of a photon between T_1 and T_2 can be derived from Eq. (14) as

$$\Delta f = f_1 - f_2 = (C_p/h)(T_1 - T_2) \equiv \quad C_T\,\Delta T, \tag{16}$$

where $C_T = C_p/h$ is the change rate of frequency over temperature. From Eq. (16), when the temperature of a photon is cooled, its frequency would be reduced, and the wavelength increased, showing that it is indeed a redshift!

Now the standard definition of (relative) Temperature Shift can be given as

$$Z_T = (f_{emit} - f_{obsr}) / f_{obsr} = (T_{emit} - T_{obsr}) / T_{obsr} = T_{emit} / T_{obsr} - 1, \tag{17}$$

where f_{emit} *and* T_{emit} are the frequency and temperature of photon at the emitting star, while f_{obser} *and* T_{obsr} are the frequency and temperature of photon immediately hit the observer.

When the temperature difference is big, the redshift is also big. For example, the surface temperature of Sun is estimated to be 5778° K, while the surface temperature of Earth is about 300° K, if photon's temperature is cooled to the Earth's temperature when it passes through the atmosphere, then (relative) Temperature Redshift Z_T as in Eq. (16) of the Sun light would be around 5778 / 300 - 1 = 18.26. This is quite a large value and is never observed. That's because when a photon from a star hits the observer's device, the temperature of the photon immediately before hitting may not necessarily be the temperate of the device, it could still be much higher because the photon may have not cooled down in the course. In the case of solar light, it takes only 8 minutes to travel to Earth, and in such a short time, its temperature mat not change very much. As will be shown in Section 6, when distance is really small, the Doppler Redshift also cannot be ignored.

Because the temperatures and distances of stars or galaxies can be much higher, Temperature Redshift, if physically proven, can explain large values of redshifts, while Doppler Redshift can hardly do so, as shown in Section 2.

5. The Relation between Temperature Redshift and distance

Now let's find the relation between Temperature Redshift and distance. Assume the temperature of photon cools off when it travels through the Universe linearly with distance as follows:

$$T_{obsr} = T_{emit} - k_H D\, T_{emit} \quad = (1 - k_H D)\, T_{emit} \qquad (18)$$

where k_H is the cooling-off coefficient of photon over distance, D the distance of the star to the observer. In Eq. (18) we are using distance D instead of traveling time t to avoid the effect of special relativity. That's another advantage of Temperature Redshit: Special relativity principle has no effect on temperature. Now applying Eq. (18) to Eq. (17) and reformulate it as follows:

$$Z_T = (f_{emit} - f_{obsvr}) / f_{obsvr} \quad = (T_{emit} - T_{obsvr}) / T_{obsvr} = \quad (k_H D) / (1 - k_H D) \qquad (19)$$

where Z_T is the Temeperature Redshift. From the above we can get

$$D = \frac{Z_T}{k_H (1 + Z_T)} \qquad (20)$$

Eq. (20) is very important, because it gives a calculation of the distance from Temperature Redshift alone.

When the speed of a star is small, then its Doppler Red shift is negligible. For example, when v = 0.1c in Eq. (1), the Doppler Redshift would be 0.1055416, far smaller than the smallest redshift value 5.2 scientists have measured so far ([4]). So, as a first step, Eq. (20) would give a rough estimate of the distance of the star from Z_T values alone. And the nice thing with Eq. (20) is that it involves only the Temeperature Redshift value and a constant k_H, which we shall call Distance Coefficient of Temperature Redshift.

Now lets's find out what k_H is. Obviously, the cooling-off coefficient k_H can also be determined experimentally, but here we shall derive its relation with the Hubble constant H_0. Re-arrange Eq. (19) we can get

$$Z_T / D = \quad k_H \;/ (1 - k_H D) = 1 / (1/k_H - D) \qquad (21)$$

Eq. (21) leads to two special cases when D takes two special values.

First, when D << 1 / k_H, Eq. (21) becomes:

$$Z_T / D = k_H \quad (22)$$

which looks like the same as Eq. (7), the *observational* Hubble's Law. Comparing Eq. (7) and (22) might suggest

$$k_H = H_0 / c = 1 / r_{HS}, \quad (23)$$

where $r_{HS} = c / H_0$ is the Hubble Length ([25]). As we shall see in next Section, in general, $k_H \neq r_{HS}$, because in the generic case, redshift contains both Temperature Redshift and Doppler Redshift, therefore, not only Hubble's Law need to be revised, but also the Hubble's constant.

Second, when D = 1/ k_{HS}, Eq. (21) would give an infinite value for Z_T/D. This means Z_T/D becomes immeasurable. This gives a much better explanation of the Hubble Sphere. With the current theory, outside of the Hubble Sphere, the receding star would have a speed that is larger than light speed, contradicting with the special relativity principle, and some non-convincing excuse has to be used to explain this contradiction ([21]).

It is now obvious that distance is related to Temperature Redshift through Eqs. (20)-(22), while with Doppler Redshift as expressed in Eqs. (1) and (3), distance is not directly related to Doppler redshift.

Thus far we have derived an equation (Eq. (6)) quite similar to *observational* Hubble's Law (Eq. (7)) from a few purely theoretic, but very reasonable assumptions for the first time. Till this date, the observational Hubble's Law is only an observational fact. As such, it is quite possible that the Hubble's Law in most part reflect the effect of Temperature Redshift rather than the Cosmologic Redshift or Doppler Redshift. In addition, because Doppler Redshift is negligible for slow moving celestial bodies, Eqs. (20)-(22) give much better info. on redshift and distance.

Now, to understand the application limit of Temperature Redshift, let's assume the equilibrium temperature in the empty space of the Universe is T_0. When a photon travels long enough, it will reach this equilibrium temperature. From Eq. (18) we can calculate the distance D_0 that is needed for a photon to reach the equilibrium temperature T_0:

$$D_0 = (1 - T_0 / T_{emit}) / k_H \quad = (1 - T_0 / T_{emit}) \, r_{HS} \quad (23)$$

For stars, typically T_0 / T_{emit} is close to zero, and in this case, D_0 *is* the same as the Hubble Length. However, Eq. (23) states that the maximum measurable distance by Temperature Redshift is usually smaller than the Hubble Length, depending on the temperature of the star and the equilibrium temperature of the empty space in the Universe. When distance is larger than D_0, the observer would get the same redshift as if the photon comes from distance D_0.

The above discussion gives a new explanation of the Hubble's Length, without violating the special relativity principle. That is, outside of the Hubble's Sphere, the light of the star can still be seen by observer at the center of the Hubble's Sphere, but the redshift value would be the same as if it is from the surface of the Hubble's Sphere.

6. When multiple redshifts are present

Eq. (19) applies to stars moving with any speed, because no time and velocity is involved (hence special relativity has no effect). When the speed of a star is high, its Doppler Redshift cannot be ignored. In this case, we would have a complicated situation in which both Temprature Redshift and Doppler Redshift will need to be considered.

First, let's conisder the more generic case of Doppler Redshift ([27]):

$$Z_d = (1 + v\cos(\theta) / c) / \sqrt{1 - v^2 / c^2} - 1 \qquad (24)$$

where θ is the angle of the speed of the star to the line of sight. The redshift observed could be a combination of the Temperature Redshift and Doppler Redshift, as follows:

$$Z = Z_T + Z_d = (k_H D) /(1- k_H D) + (1 + v\cos(\theta) / c) / \sqrt{1 - v^2 / c^2} - 1 \qquad (25)$$

In the above equation, we have three unknowns on the right side, distance D, velocity v, and angle θ. Then we need at least three redshift measurements at long time intervals or additional information (e.g. luminosity measurement on D) on distance D or v, in order to solve for D or v from the observed redshift Z, as there is no way to separate Temperature Redshift and Doppler Redshift from the Spectrum Line. Complicated triangulation is also involved in doing so. Fortunately, when stars with high temperatures and a speed less than 0.3c, Doppler Redshift can be ignored and Temperature Redshift alone can be assumed in calculating distance.

In addition, if Cosmologic Redshift is also involved, then adding Eq. (10) to both sides of Eq. (25) leads to:

$$Z = Z_T + Z_C + Z_d = (k_H D) /(1- k_H D) + (H_c / c) D + (1 + v\cos(\theta) / c) / \sqrt{1 - v^2 / c^2} - 1 \qquad (26)$$

For stars like Sun, both the relative speed and distance of Sun with Earth are small, in this particular situation, when $\theta = 0^o$, we would get from Eq. (20)

$$Z = Z_T + Z_C + Z_d = k_H D + (H_c/c) D + v/c = (k_H + H_c/c) D + v/c \qquad (27)$$

Eq. (27) shows a linear (affine) relation between the total observed redshift Z and the distance D, though the constant v/c is different for each star. When computing the Hubble constant from the observational Hubble's Law (Eq. (7)), v/c is not there, and this might be the major reason that the academic community cannot agree on the Hubble constant ([19]). However, in a non-expansion region, for slow moving stars at long distance, e.g., $H_c/c \ll k_H$, *and* $v/c \ll k_H D$, Eq. (27) reduces to Eq. (22), which has the form of Eq. (7) (the observational Hubble's Law). As such, on the large, H_0 / c as measured in numerous observations could mainly, in fact, reflect the contribution of k_H.

As discussed above, from the relation between Doppler Redshift and velocity as in Eq. (24), there is no relation between the Doppler Redshift and the distance. Though Cosmologic Redshift is related to distance, its expansion rate $a(t_{obsvr}) / a(t_{emit})$ cannot be measured from the redshift if Temperature Redshift is also there. The observational Hubble's Law as in Eq (7) is only true for slow moving stars in distances far samller than $1/k_H$, and even in this case, the constant H_0 / c reflects the sum $(k_H + H_c/c)$, or

$$H_0 = k_H * c + H_c \qquad (28)$$

Therefore, to extend Eq. (7), Eq. (25), or Eq, (26) to the postulated Hubble's Law(Eq. (5)) may be a incorrect step, especially for large v/c. On the other hand, the new law Eq. (21) or Eq. (26) derived from Temperature Redshift explains the observational Hubble's Law very well, even for large distance.

In Eq. (26), if Temperature Redshift does not exist, then all we have to do is to set $k_H = 0$. Similarly, if Cosmologic Redshift does not exist, then $H_c = 0$. Therefore, Eq. (26) is a more generic formula for redshift, even in case Cosmologic Redshift does exist in a local galaxy.

7. Conclusion

This article has first shown that absurdity could arise from attributing the redshift of celestial bodies mainly to Doppler Redshift alone or to Cosmologic Redshift alone, and that the *postulated* Hubble's Law is an improper generalization of the *observational* Hubble's Law. Then by assuming photon has temperature and its thermal energy is fully converted to wave energy, we come to the conclusion that photon can have Temperature Redshift, which is shown to explain the redshifts of celestial bodies far better than Cosmological Redshift and Doppler Redshift. Surprisingly, it is shown that the *observational* Hubble's Law can be a special case of the effect of the Temperature Redshift. While Temperature Redshift and Cosmologic Redshift can co-exist to explain the observational Hubble's Law for slow moving stars, any expansion of the Universe suggests it has to expand with acceleration which requires enormous forces constantly to exert on each star according to its mass. As such, an expanding Universe model is not only not necessarily needed to explain the refshift data, but also leads to many impossible things with extremely low probability.

References

1. Rothman, L.S. et al., "The HITRAN2012 molecular spectroscopic database", *Journal of Quantitative Spectroscopy and Radiative Transfer,* pp. **130**: 4–50, ISSN 0022-4073 (2013).
2. Gabrielse, Gerald; H. Dehmelt, "Observation of Inhibited Spontaneous Emission", *Physical Review Letters*. **55** (1): 67–70 (1985).
3. Peach, G., "Theory of the pressure broadening and shift of spectral lines", *Advances in Physics*. **30** (3): 367–474, (1981).
4. Binney, James & Michael Merrifeld, *Galactic Astronomy,* Princeton University Press, ISBN 978-0-691-02565-0 (1998).
5. Carroll, Bradley W. & Dale A. Ostlie, *An Introduction to Modern Astrophysics,* Addison-Wesley Publishing Company, Inc., ISBN 978-0-201-54730-6 (1996).
6. Kutner, Marc, *Astronomy: A Physical Perspective,* Cambridge University Press, ISBN 978-0-521-52927-3 (2003).
7. Peebles, P.J.E., *Principles of Physical Cosmology*, Princeton University Press, ISBN 978-0-691-01933-8 (1993).
8. Liddle, A. R., *An Introduction to Modern Cosmology* (2nd ed.), John Wiley & Sons, ISBN 978-0-470-84835-7 (2003).
9. Hawley, John F. and Holcomb, Katherine A., *Foundations of modern cosmology* (2nd ed.), Oxford Univ. Press. p. 304, ISBN 978-0-19-853096-1 (2005).
10. Hubble, Edwin, "A Relation between Distance and Radial Velocity among Extra-Galactic Nebulae", *Proceedings of the National Academy of Sciences of the United States of America,* **15** (3): 168–173 (1929).
11. Odenwald, S. & Fienberg, RT, "Galaxy Redshifts Reconsidered", *Sky & Telescope,*

pp31–35 (2003).
12. Harrison, E., "The redshift-distance and velocity-distance laws". *The Astrophysical Journal,* **403:** 28–31 (1992).
13. Lemaître, G., "Un univers homogène de masse constante et de rayon croissant rendant compte de la vitesse radiale des nébuleuses extra-galactiques". *Annales de la Société Scientifique de Bruxelles A*. **47**: 49–59, 1927. Partially translated in Lemaître, G., "Expansion of the universe, A homogeneous universe of constant mass and increasing radius accounting for the radial velocity of extra-galactic nebulae". *Monthly Notices of the Royal Astronomical Society*. **91** (5): 483–490 (1931).
14. Hubble, E. P., *The Observational Approach to Cosmology*. Clarendon Press, LCCN 38011865 (1937).
15. Freedman, W. L.; Madore, B. F., "The Hubble Constant". *Annual Review of Astronomy and Astrophysics*. **48**: 673–710 (2010).
16. Livio, M., "Lost in translation: Mystery of the missing text solved". *Nature*. **479** (7372): 171–3 (2011).
17. Livio, M.; Riess, A., "Measuring the Hubble constant", *Physics Today,* **66** (10): 41 (2013).
18. Wall, Mike, "The Universe Is Expanding So Fast We Might Need New Physics to Explain It", *Space.com, 04/25 (2019).*
19. Sokol, Joshua, "Debate intensifies over speed of expanding universe". *Science*, 07/20 (2019).
20. Lineweaver, Charles H. and Tamara M. Davis, "Misconceptions about the Big Bang", *Scientific American*, 03 (2005).
21. Overbye, Dennis, "The Flip Side of Optimism About Life on Other Planets". *The New York Times, 08/03 (2015)*.
22. Eddington, Arthur, *The Expanding Universe: Astronomy's 'Great Debate', 1900–1931,* Cambridge University Press, ISBN 978-0-521-34976-5 (1933).
23. Harrison, Edward Robert, *Cosmology: The Science of the Universe* (2nd ed.). Cambridge University Press, ISBN 978-0-521-66148-5 (2000).
24. Keel, W. C., *The Road to Galaxy Formation* (2nd ed.), Springer, pp. 7–8, ISBN 978-3-540-72534-3 (2007).
25. Freedman, W. L.; et al. (2001). "Final results from the Hubble Space Telescope Key Project to measure the Hubble constant". *The Astrophysical Journal*. **553** (1): 47–72 (2001).
26. Weinberg, S., *Cosmology*, Oxford University Press, ISBN 978-0-19-852682-7 (2008).
27. Freund, Jurgen, *Special Relativity for Beginners,* World Scientific, ISBN 978-981-277-160-5 (2008).
28. Halliday, David et al., *Fundamentals of Physics* (7th ed.), John Wiley and Sons, ISBN 978-0-471-23231-5 (2005).
29. Weaver, Donna; Villard, Ray; Hille, Karl, "Improved Hubble Yardstick Gives Fresh Evidence for New Physics in the Universe", *NASA, 02/22* (2018).
30. Christian G. Bohmer, *Introduction to General Relativity and Cosmology, World Scientific,* ISSN: 2059-7630 (2017).