

## Cosmology Model Preface

While the information in this preface is well-known to cosmologists, it is being explained for the nonscientist users.

The purpose of this model is to provide a simple and easy-to-use interface for the calculation of various cosmological values and to allow **nonscientists** to obtain a good spatial understanding of the expansion of the universe.

The model focuses primarily on the “**visible universe**” and how that space has expanded since light (**photons**) first began to stream across the universe approximately 380,000 years after the beginning of the universe (the “**Big Bang**”). The furthest visible photons are known as the “last scattering surface” or “**LS**.”

The model **produces calculations of various distances and times when certain events occurred** during the expansion of the universe. The model also shows when the expansion of the universe began “**accelerating**” along with many other expansion rate values at different times during the evolution of the universe.

Additionally, the user may request **tables of “z” values** with many pages of calculations of different cosmological parameters at different times.

More knowledgeable users may **move the “Observer”** from Earth today to points either in the past or in the future in order to see conditions that would have been (or will be) observed at that time.

## The “Visible Universe”

It is important to understand that the model is primarily designed to define the universe in terms of the farthest visible light that cosmologists can detect. This light, now commonly referred to as the **Cosmic Microwave Background (CMB)** began streaming across the universe from everywhere toward everywhere else at the **LS** (last scattering mentioned above).

The **LS** could not occur until all the matter in the universe had sufficiently separated and cooled due to the rapid expansion of space from the time of the “**Big Bang**” until approximately 380,000 years later.

It is believed that the rapid expansion of space and the associated cooling allowed the sub-atomic constituent material to form into electrons, neutrons, protons, etc. and that led to the formation of hydrogen and other molecules. This activity required the universe to cool to approximately 3000 °Kelvin (4940 °Fahrenheit or 2727 °Celsius). For more in-depth information, please see:

[https://en.wikipedia.org/wiki/Cosmic\\_microwave\\_background](https://en.wikipedia.org/wiki/Cosmic_microwave_background)

[https://en.wikipedia.org/wiki/Decoupling\\_\(cosmology\)](https://en.wikipedia.org/wiki/Decoupling_(cosmology))

[http://ned.ipac.caltech.edu/level5/Glossary/Essay\\_Iss.html](http://ned.ipac.caltech.edu/level5/Glossary/Essay_Iss.html)

### The “z Scale”

Once these photons started streaming across the universe, **space continued to expand rapidly**. This expansion led to the phenomena known as “**redshifted light**” and to the use of a new scale – the **z scale** – which plays a very important role in the calculations of times and distances related to objects seen by astronomers.

The z Scale starts from **z=0.000 for close-by objects** – such as stars in the Milky Way galaxy – meaning that the light from these stars reach Earth without any meaningful expansion of space between the star and Earth by the time that light reaches Earth. The z Scale at the **farthest visible light is around z=1089 to z=1100** (this would be the **CMB**).

The z Scale normally ranges between z=0.000 and z=1100 for events that are visible today. **However, the z Scale can also range in the other direction – from z=0.000 to z=-1.000 for future events** that are not yet visible but can be predicted. See “**How to Move the Observer to the Future**” documentation for additional information.

The **z scale** is a non-linear scale. For example, if a **galaxy located at z=3.000 emitted light** that we just now see today, the implication is that **the emitted light left the galaxy at the same time that the CMB photons we also just now see today passed by that galaxy**. It further means that the **distance between Earth and the galaxy from that moment until now, has increased by a factor of 4.000 (z + 1.000)**.

In other words, the distance to that galaxy today is the original distance from Earth when the light was emitted from the galaxy plus an expansion of an additional 3.000 times that distance for a total of 4.000 times the original distance.

For example, if the distance to a  $z=3.000$  galaxy at the time the light was emitted was **5.285 billion light years** from Earth's future location (**known as the Proper Distance**), then that galaxy would now be **21.140 billion light years** from Earth today (**known as the Comoving Distance**) ( $4.000 \times 5.285 = 21.140$ ). This will be discussed in the **Default Output Documentation**.

To further demonstrate the non-linear nature of the  $z$  scale – using the same  $z=3.000$  example – the light which started toward Earth's position from **5.285 billion light years away** actually traveled for **11.549 billion years** in order to reach Earth (due to the expansion of space). **That is a time ratio of 2.185 rather than the distance ratio of 4.000 above.**

**See the  $z$  Scale example table on the next page and a Spatial Orientation of the Earth ( $z=0.000$ ), a galaxy located at  $z=3.000$ , and the CMB ( $z=1091.000$ ) on the following page.**

It is important to understand that the farthest object that is generally visible to the naked eye, **the Andromeda Galaxy**, is located at near  $z=0.0002$ . Only advanced ground-based receivers or satellite receivers positioned above the atmosphere can detect  $z$  values beyond the **2.5 million light years** to reach the Andromeda Galaxy. **A single light year is approximately 5.9 trillion miles.**

**The model begins by positioning the Observer at  $z=0.000$  (today) and uses the Default Input Form data for the first calculations. The user may then make changes to the Input data and the model will then produce results using the changed data.**

The table below demonstrates just how non-linear the z scale is:

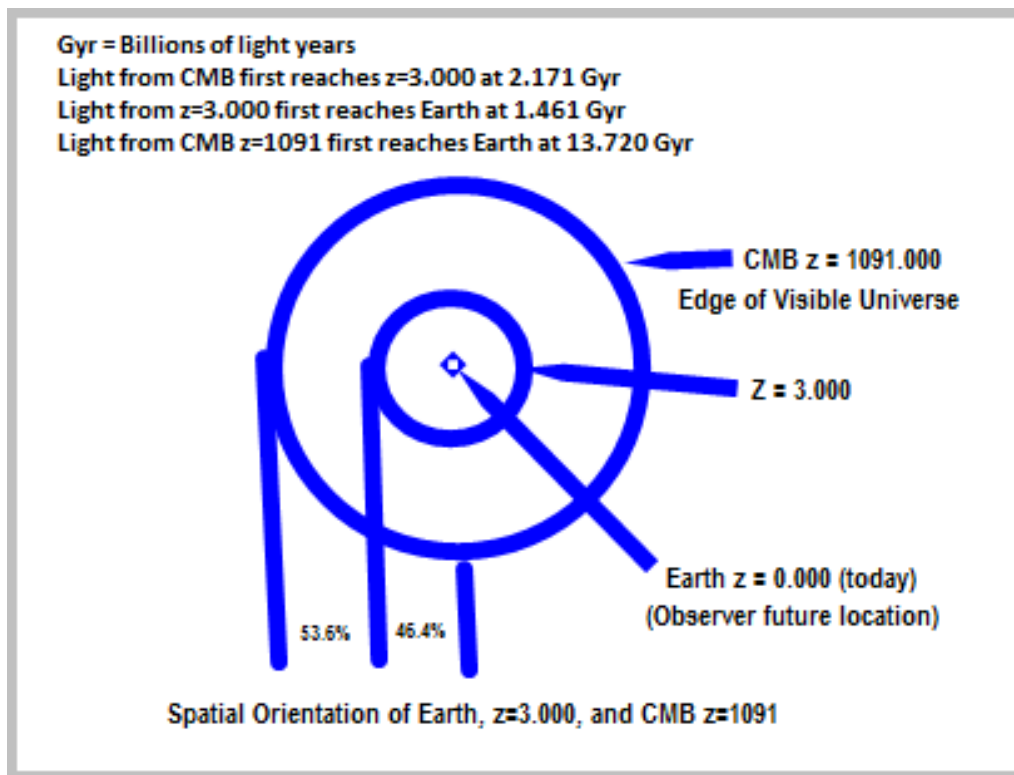
CMB Evolution by z from Observer Location						
Geometry Option = [General]		Points/Integral = 1,000		Observer at z = 0.000		
Hubble Constant (Ho) = 69.600		Omega(m) = 0.2860		Omega(r) = 0.00008598		
Current CMB = 1091.000		Omega(vac) = 0.7140		Omega(k) = 0.00008598		
z Scale	Age when Light from z point first reached Earth	Distance from Earth to z point at that Age	Age when CMB* light first reached z point	Proper Distance Earth to z point when CMB* Hit z	Distance from Earth to z point Now (Comoving)	Pct of Distance from Earth to CMB*
Redshift (z)	(years)	(ly)	(years)	(ly)	(ly)	(%)
0.000	374,666	0	13,720,645,822	0	0	0.000
0.020	690,808	375,136	13,443,637,589	274,277,979	279,763,539	0.614
0.040	1,123,210	1,002,612	13,174,381,441	535,656,826	557,083,099	1.222
0.060	1,683,763	1,920,564	12,912,610,708	784,838,281	831,928,578	1.825
0.080	2,383,629	3,165,035	12,658,070,999	1,022,474,755	1,104,272,735	2.423
0.100	3,233,171	4,769,767	12,410,519,315	1,249,173,798	1,374,091,177	3.015
0.200	10,034,061	19,216,047	11,269,779,619	2,237,199,297	2,684,639,156	5.891
0.300	21,692,870	46,421,912	10,272,644,759	3,023,038,078	3,929,949,502	8.625
0.400	38,702,429	88,189,351	9,397,938,307	3,649,897,249	5,109,856,148	11.216
0.500	61,216,417	145,275,385	8,628,005,556	4,150,297,777	6,225,446,665	13.665
0.600	89,135,128	217,643,361	7,947,998,454	4,549,224,792	7,278,759,667	15.978
0.700	122,183,615	304,695,491	7,345,368,704	4,866,174,835	8,272,497,219	18.161
0.800	159,975,925	405,466,784	6,809,483,432	5,116,542,634	9,209,776,742	20.219
0.900	202,065,746	518,779,595	6,331,318,358	5,312,595,750	10,093,931,925	22.161
1.000	247,983,097	643,357,316	5,903,204,810	5,464,181,123	10,928,362,247	23.994
1.500	519,433,353	1,391,742,120	4,315,769,067	5,786,928,352	14,467,320,880	31.768
2.000	828,524,023	2,257,410,831	3,316,314,141	5,732,699,933	17,198,099,800	37.767
2.500	1,147,042,761	3,158,180,387	2,645,394,197	5,533,789,918	19,368,264,714	42.535
3.000	1,460,567,537	4,051,164,537	2,171,463,679	5,284,773,065	21,139,092,261	46.426
4.000	2,049,487,693	5,742,668,602	1,557,943,456	4,774,388,096	23,871,940,478	52.431
5.000	2,577,907,311	7,275,077,298	1,186,313,437	4,316,988,656	25,901,931,937	56.891
5.500	2,820,070,606	7,982,028,547	1,052,308,236	4,113,592,535	26,738,351,480	58.729
6.000	3,048,672,194	8,652,183,236	941,686,072	3,926,314,131	27,484,198,918	60.368
7.000	3,469,043,693	9,891,905,720	770,747,318	3,595,187,427	28,761,499,417	63.174
8.000	3,846,416,961	11,013,425,860	645,817,619	3,313,371,188	29,820,340,695	65.501
9.000	4,187,257,892	12,033,828,955	551,269,172	3,071,647,563	30,716,475,626	67.470
10.000	4,496,960,346	12,967,513,512	477,687,180	2,862,511,238	31,487,623,613	69.164
25.000	7,212,769,120	21,475,417,704	130,722,230	1,423,422,843	37,008,993,915	81.297
90.000	10,420,897,024	32,527,996,918	19,512,272	459,011,884	41,770,081,461	91.760
545.000	13,145,722,389	43,105,054,187	1,177,433	82,273,909	44,921,554,150	98.696
1091.000	13,720,645,822	45,508,473,670	374,666	41,674,426	45,508,473,670	100.000

\* CMB refers to the current CMB surface -- the actual z value for this surface at earlier times would have been lower.

**Default Input Form value of Z=3.000 shown in yellow.**

See graphic on next page for additional explanation of these column values.

## Spatial Orientation of Earth, $z=3.000$ , and the CMB



The spatial orientation today for  $z=3.000$  at 46.4% of the distance from Earth's location to the current CMB is the same relative percentage as it was all the way back at the time of the Last Scattering (LS) for the same three points. This relative location percentage is just about the only number that does not change as space constantly expands across the universe.

While this may all seem confusing at first, the more the user works with the model and the various  $z$  Tables, the clearer it will become just how quickly the expansion of space began and how that expansion affected the spatial positioning of the galaxies and other light sources that astronomers see today.

One final table that shows relative positioning of each z value. Note the CMBz photon crosses the 1.000 expansion rate to Earth at z = 1.622403.

		Relative Earth, Future z, and CMBz Locations						
Geometry Option = [General]		Points/Integral = 1,000		Observer at z = 0.000 (Earth)				
Hubble Constant (Ho) = 69.600		Omega(m) = 0.2860		Omega(r) = 0.00008598				
Current CMBz = 1091.000		Omega(vac) = 0.7140		Omega(k) = 0.00008598				
Fut(z)	Fut(z) Pct of Earth to CMBz Distance		Distance from Earth to Fut(z)	Distance from CMBz to Fut(z)	Distance from z location to CMBz Today	CMBz Photon to Earth	Expansion Rate from Earth to	
Location z Scale Fut(z)	Viewed from Earth (%)	Viewed from CMBz (%)	at Last Scatter (ly)	at Last Scatter (ly)	z Location to CMBz Today (ly)	Distance at z (ly)	Fut(z) at z Age (ly/y)	Age at z (years)
0.000	0.000%	100.000%	0	41,674,426	45,508,473,670	0	0.000	13,720,645,822
0.010	0.308%	99.692%	128,168	41,546,259	45,368,288,397	138,797,300	0.010	13,581,155,522
0.020	0.614%	99.386%	255,785	41,418,641	45,228,710,131	274,277,979	0.020	13,443,637,589
0.030	0.919%	99.081%	382,848	41,291,578	45,089,742,905	406,534,723	0.029	13,308,057,470
0.040	1.222%	98.778%	509,354	41,165,072	44,951,390,571	535,656,826	0.039	13,174,381,441
0.050	1.524%	98.476%	635,298	41,039,128	44,813,656,802	661,730,351	0.048	13,042,576,574
0.060	1.825%	98.175%	760,678	40,913,749	44,676,545,092	784,838,281	0.057	12,912,610,708
0.070	2.125%	97.875%	885,489	40,788,937	44,540,058,757	905,060,666	0.066	12,784,452,421
0.080	2.423%	97.577%	1,009,730	40,664,697	44,404,200,935	1,022,474,755	0.075	12,658,070,999
0.090	2.720%	97.280%	1,133,397	40,541,030	44,268,974,586	1,137,155,123	0.084	12,533,436,419
0.100	3.015%	96.985%	1,256,487	40,417,940	44,134,382,493	1,249,173,798	0.093	12,410,519,315
0.200	5.891%	94.109%	2,455,202	39,219,224	42,823,834,514	2,237,199,297	0.175	11,269,779,619
0.300	8.625%	91.375%	3,594,478	38,079,949	41,578,524,168	3,023,038,078	0.249	10,272,644,759
0.400	11.216%	88.784%	4,674,082	37,000,345	40,398,617,522	3,649,897,249	0.318	9,397,938,307
0.500	13.665%	86.335%	5,694,955	35,979,471	39,283,027,005	4,150,297,777	0.383	8,628,005,556
0.600	15.978%	84.022%	6,658,927	35,015,500	38,229,714,003	4,549,224,792	0.445	7,947,998,454
0.700	18.161%	81.839%	7,568,442	34,105,985	37,235,976,451	4,866,174,835	0.504	7,345,368,704
0.7092	18.355%	81.645%	7,649,479	34,024,947	37,147,438,237	4,891,782,959	0.510	7,293,427,507
0.800	20.219%	79.781%	8,426,335	33,248,092	36,298,696,928	5,116,542,634	0.562	6,809,483,432
0.900	22.161%	77.839%	9,235,642	32,438,784	35,414,541,745	5,312,595,750	0.619	6,331,318,358
1.000	23.994%	76.006%	9,999,465	31,674,961	34,580,111,423	5,464,181,123	0.674	5,903,204,810
1.500	31.768%	68.232%	13,239,239	28,435,188	31,041,152,790	5,786,928,352	0.938	4,315,769,067
1.622403	33.376%	66.624%	13,909,349	27,765,078	30,309,209,072	5,795,930,144	1.000	4,029,861,333
2.000	37.767%	62.233%	15,739,387	25,935,039	28,310,373,870	5,732,699,933	1.186	3,316,314,141
2.500	42.535%	57.465%	17,726,376	23,948,051	26,140,208,956	5,533,789,918	1.420	2,645,394,197
3.000	46.426%	53.574%	19,347,790	22,326,636	24,369,381,409	5,284,773,065	1.641	2,171,463,679
3.500	49.672%	50.328%	20,700,565	20,973,861	22,891,984,438	5,025,886,496	1.852	1,822,853,182
4.000	52.431%	47.569%	21,850,137	19,824,289	21,636,533,192	4,774,388,096	2.054	1,557,943,456
4.500	54.811%	45.189%	22,842,055	18,832,371	20,553,270,558	4,537,309,657	2.246	1,351,220,287
5.000	56.891%	43.109%	23,708,962	17,965,464	19,606,541,733	4,316,988,656	2.431	1,186,313,437
5.500	58.729%	41.271%	24,474,867	17,199,560	18,770,122,190	4,113,592,535	2.609	1,052,308,236
6.000	60.368%	39.632%	25,157,840	16,516,587	18,024,274,752	3,926,314,131	2.781	941,686,072
6.500	61.841%	38.159%	25,771,760	15,902,667	17,353,841,801	3,753,950,916	2.947	849,120,853
7.000	63.174%	36.826%	26,327,475	15,346,952	16,746,974,253	3,595,187,427	3.108	770,747,318
7.500	64.389%	35.611%	26,833,601	14,840,826	16,194,263,206	3,448,730,643	3.264	703,700,603
8.000	65.501%	34.499%	27,297,073	14,377,353	15,688,132,975	3,313,371,188	3.416	645,817,619
8.500	66.524%	33.476%	27,723,548	13,950,879	15,222,408,008	3,188,006,912	3.564	595,438,146
9.000	67.470%	32.530%	28,117,684	13,556,742	14,791,998,044	3,071,647,563	3.708	551,269,172
9.500	68.347%	31.653%	28,483,364	13,191,063	14,392,665,361	2,963,410,315	3.848	512,290,402
10.000	69.164%	30.836%	28,823,846	12,850,581	14,020,850,057	2,862,511,238	3.986	477,687,180
25.000	81.297%	18.703%	33,880,012	7,794,414	8,499,479,755	1,423,422,843	7.212	130,722,230
53.600	88.275%	11.725%	36,787,962	4,886,465	5,324,126,276	735,977,058	11.396	42,509,109
67.250	89.909%	10.091%	37,469,149	4,205,278	4,580,351,157	599,679,451	13.003	30,272,558
90.000	91.760%	8.240%	38,240,315	3,434,112	3,738,392,209	459,011,884	15.374	19,512,272
135.500	93.944%	6.056%	39,150,712	2,523,714	2,744,600,033	313,288,452	19.405	10,467,615
181.000	95.238%	4.762%	39,689,809	1,984,617	2,156,320,309	238,198,645	22.864	6,706,249
272.000	96.758%	3.242%	40,323,379	1,351,047	1,465,401,115	161,329,936	28.816	3,558,393
363.000	97.653%	2.347%	40,696,243	978,183	1,059,269,588	122,113,198	34.002	2,257,445
545.000	98.696%	1.304%	41,130,829	543,597	586,919,520	82,273,909	43.112	1,177,433
1091.000	100.000%	0.000%	41,674,426	0	0	41,674,426	65.977	374,666

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