

## Cosmic Chemistry: Cosmogony

## Cosmic Tug of War

## STUDENT TEXT

You began the study of Cosmogony by examining and working with models that focused on the concepts of gravity, density, Doppler shifts, fundamental particles, and their part in the history of the cosmos. As you completed these activities, you found that:

- The physical laws of thermodynamics and the properties of fundamental forces apply not only to the present universe, but can also be used to envision the history of the cosmos and to predict its future.
- The history of the quark model, based on these laws, showed how the cosmos might have evolved from a state of high density and high energy.
- Doppler shifts are used to study the direction and extent of cosmic expansion at the present time.
- Large luminous clusters, superclusters, and voids form what may be an isotropic and homogeneous cosmos.
- Gravitational force, a major component of the universe, is the basis for studies of galactic dynamics that indicate that there is more mass in the universe than luminous matter can account for.
- Determining the density of the present universe is a difficult problem because of the differences in mass of cosmic structures and voids and the indirect evidence for the presence of dark matter.

The activities in this module, therefore, gave you the opportunity to consider some of the current evidence that supports the basic precepts of the standard cosmological model, which are shown in the box below.

**Basic Precepts of the Standard Cosmological Model**

1. The physical laws adduced on the Earth pertain throughout the observable universe.
2. The universe is expanding.
3. The universe is isotropic and homogeneous.
4. General relativity accurately describes the behavior of gravitation in the universe today.
5. The early universe was in a state of high density and high energy.
6. The universe is evolving.

Since all but one of the standard cosmological model precepts is written in the present tense, most of them pertain to the universe as it is today. Interestingly enough, two of those precepts—those describing gravity and expansion—involve forces that are in opposition to each other. In other words, there is a universal “tug of war” occurring between the force of gravity and the expansion of the universe. This means that the universe is **dynamic** (changing) rather than **static** (staying the same). The question then becomes, how is the universe changing?

Astronomers describe this “tug of war” between expansion and gravity mathematically in terms of **omega** ( $\Omega$ ), the ratio of the **actual average mass density** of the universe to the **critical density**, (the density of mass required to halt the outward expansion of the universe). The critical density is the minimum density of matter (light and dark) the universe must have in order to have sufficient gravitational attraction to halt its current expansion.

$$\Omega = \text{actual average mass density/critical density}$$

Because the gravitational attractions between galaxies, clusters and gaseous components of the universe work in opposition to the expansion rate of the universe, there are three different possibilities for the ultimate fate of the universe.

- If  $\Omega > 1$ , the universe is **closed**;
- if  $\Omega < 1$ , the universe is said to be **open**; and
- if  $\Omega = 1$ , the universe is **flat**.

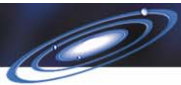
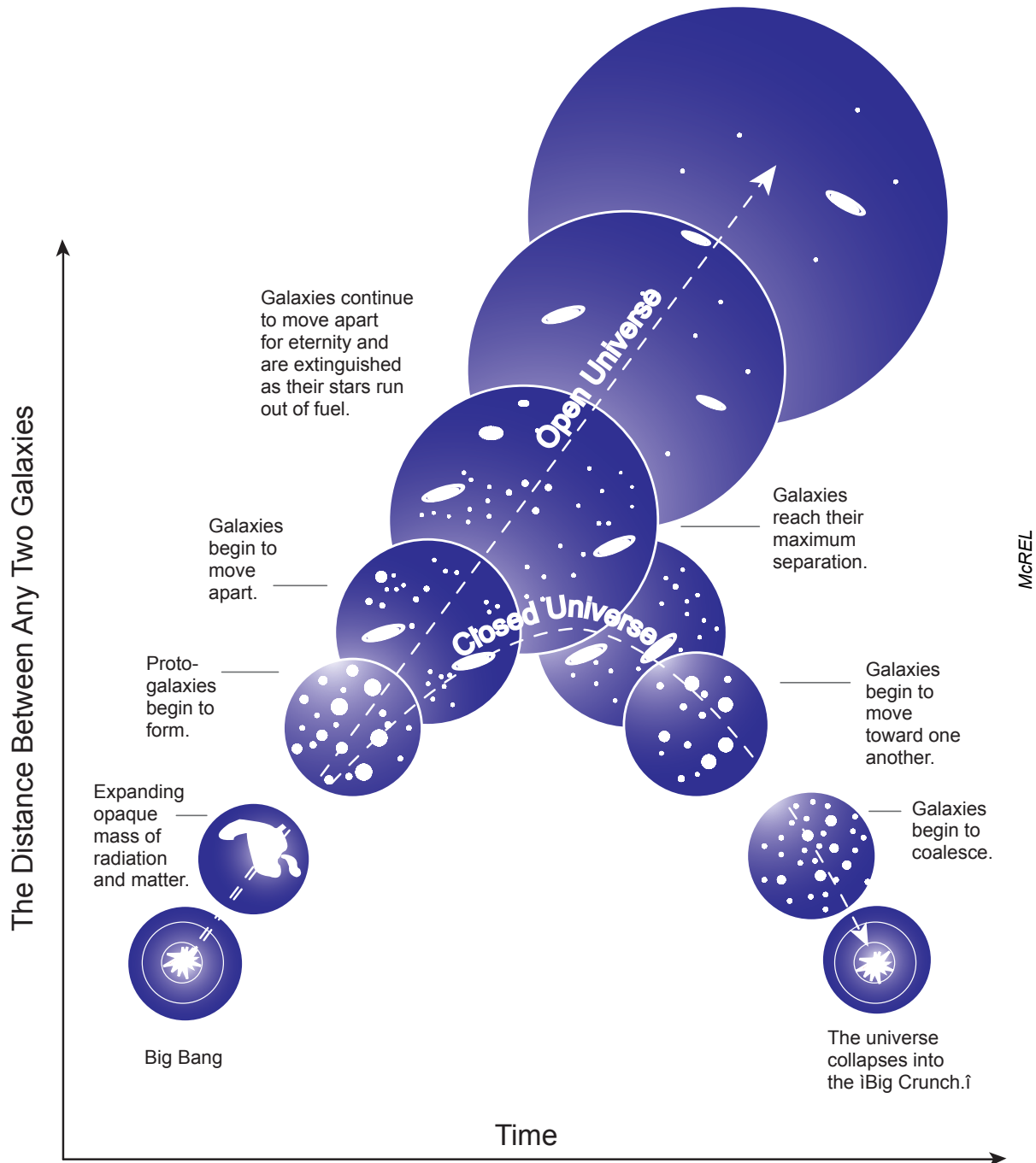


Figure 1

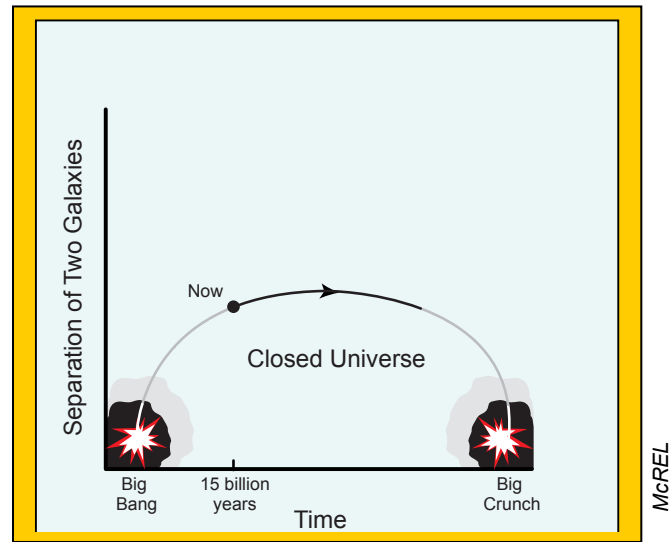


*This figure illustrates the difference between a closed and an open universe over extended time. In an open universe the galaxies expand and continue to move apart because their rate of expansion is greater than their gravitational attraction. In a closed universe, the mass of the galaxies results in a gravitational attraction that is large enough to slow the rate of expansion until the universe collapses. The flat universe is the mathematical boundary between an open and closed universe. A flat universe will stop expanding at an infinitely distant point in the future.*



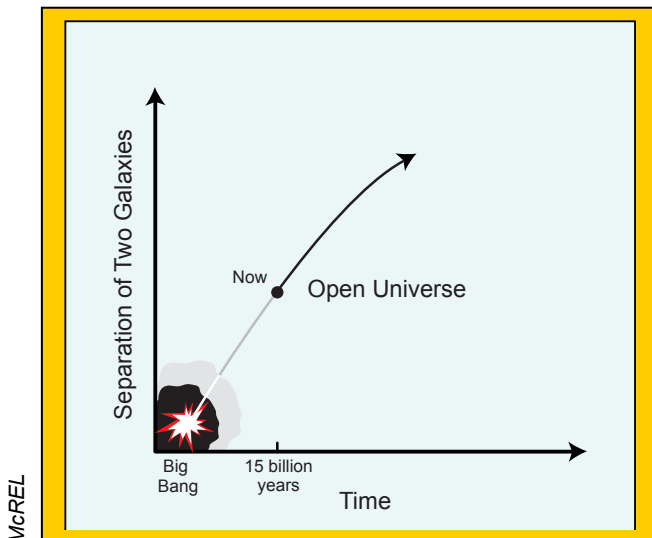
In a closed universe, where  $\Omega > 1$ , the actual average mass density is greater than the critical density. The universe is expanding slowly enough that the gravitational attraction between the different galaxies will cause the expansion to slow down and eventually to stop. Figure 2 shows a closed universe expanding and then recollapsing as space is bent in on itself. In this model, space is **finite**; that is, it has limits. Some scientists call this the “big crunch” model because it looks similar to the “Big Bang” in reverse.

Figure 2



*In a closed universe, all the galaxies initially move away from each other. So the universe expands until the gravitational attraction between the galaxies is large enough to slow the rate of expansion. The universe then contracts back to a point.*

Figure 3



*Gravity never overcomes the motion of the galaxies in an open universe, so the galaxies continue to move apart and the universe keeps expanding forever.*

In the second model, in which  $\Omega < 1$ , the universe is open. Figure 3 is a graphical illustration of this model. The actual average mass density is smaller than the critical density and the universe is expanding so rapidly that the gravitational attraction can never stop it, though it does slow it down. There is continued separation between neighboring galaxies. The universe expands forever and it never collapses inward like it does in a closed universe. Space is also **infinite** in this model.

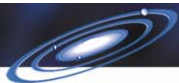
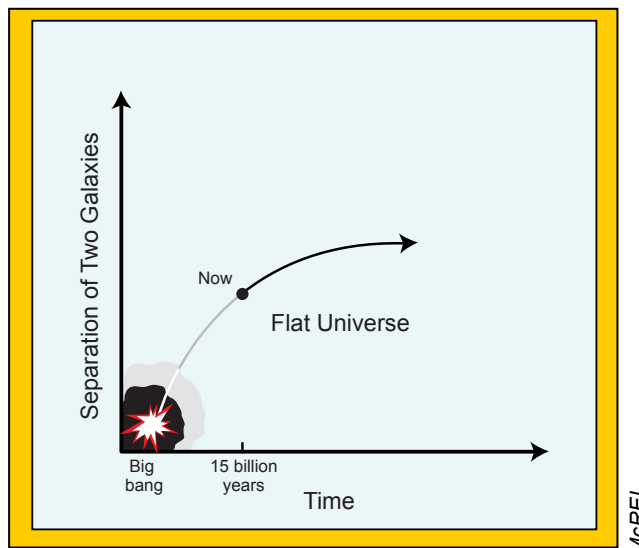


Figure 4

The third, flat model, where  $\Omega = 1$ , says the actual average mass density is equal to the critical density. In this case, the universe is expanding just fast enough to avoid recollapse. The speed at which the galaxies are moving apart will decrease, but never quite reaches zero. Note the difference in the curves shown in Figures 3 and 4. According to this model space is flat and infinite, without boundaries or restrictions.



*Gravitational attraction exactly balances the motion of the galaxies in the flat model of the universe. The universe avoids recollapse while the relative velocity of the galaxies gets slower and slower. The line showing the separation of galaxies eventually becomes "flat", showing no further separation or collapse.*

### How large is $\Omega$ ?

Which of these models describes the future universe? Theoretically, we could calculate the value of omega if we knew the present rate of expansion of the universe and its present average mass density. Practically speaking, these measurements are uncertain, difficult, and controversial.

### Rate of expansion

Astronomers have estimated the rate of universe expansion to be between 5% and 10% every billion years. The current accepted value for the rate of expansion of the universe is 20 km/sec per million light years. This value means that galaxies 1 million light years away are moving at 20 km/sec away from us, while galaxies 10 million light years away are moving at 200 km/sec, etc., implying that the rate of expansion is increasing. This relates to the mathematical models activity with the elastic activity.

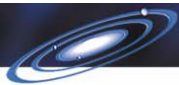
All the models presented above are based on a premise of the standard "Big Bang" model in common—that at some time in the past, the distance between neighboring galaxies must have been zero. The location of galaxies in today's universe, however, appears to be the result of more than just expansion movement; that is, the movement of galaxies away from one another. Galaxies in today's universe are not just moving away from each other; they also have small sideways velocities, so they may never have been all at exactly the same place, only very close together.

### Average mass density

The average mass density of the universe today is estimated to be about one H atom/m<sup>3</sup> of space. The uncertainty in this value, however, is even greater than that of the expansion rate because of the difficulties involved in averaging the extremely low densities of the dust and gas between the stars of our galaxy and voids between superclusters with the high densities of galaxies and superclusters. Critical density is thought to be about ten H atoms/m<sup>3</sup>.

### Homogeneity and mass of the universe

There is some consensus in the cosmic scientific community that the correct model of the future universe depends to a great extent upon two factors—the homogeneity of the universe and the amount of mass in the universe. You have already explored some aspects of these factors as you completed "The Spongy Universe" and "A Milky Way Surprise" activities. You may wish to examine these factors more closely as you decide which of the three models presented above is the correct one for our future universe.



**Homogeneity**

If matter is distributed homogeneously—smoothly and uniformly—throughout the universe on a cosmic scale, then universe expansion is the only important large-scale motion and its rate might be measured more easily. However, observers have not yet examined any large volume of space in which the distribution of galaxies is smooth.

So how do we determine the average mass density of a universe that may or may not be homogeneous on the cosmic scale? There is another way to approach this value. If astronomers knew the correct value for the rate at which cosmic expansion is slowing down, the **deceleration parameter**, they would also know the mass density of the universe. Unfortunately, this is not as simple as it may appear either.

According to the “Big Bang” model, all cosmic structures—galaxies, groups, clusters, clouds, superclusters, and supercluster complexes—resulted from the gravitational attraction of microscopic heterogeneities in the early universe. Each concentration of mass generates a gravitational field that influences the motions of galaxies within it and, to a lesser extent, those beyond.

Clusters have higher density than groups, but both groups and clusters are **gravitationally bound**. This means that their galaxies are held together by gravity and not drawn apart by the expansion of the universe. This cluster gravitational attraction is a “cosmic brake,” slowing down universe expansion. Although larger structures are stretched by cosmic expansion, their gravity retards the local expansion rate. So, if there is sufficient mass in the universe, the mutual gravitational attraction of all mass will ultimately halt the expansion; it could even cause the universe to start contracting. Galaxies in the local group are not moving away from us because of the large mass/gravity of the Milky Way affects them more than the expansion of space.

**Mass**

Estimating the amount of luminous matter in the universe, a relatively easy thing to do, results in a density of luminous matter of somewhere between 1 to 2 percent. By actually totaling the masses of all visible stars in our galaxy and other galaxies, with some accuracy, the amount of bright (luminous) matter present is less than one percent of the amount required to halt the expansion of the universe. Omega for a galaxy is the ratio of the average mass density to the critical density. Note the  $\Omega$  value of 0.002 for a visible galaxy in Table 1 below.

But galaxy dynamics reveal a different story. As we found in “A Milky Way Surprise,” the luminous disk of a galaxy is accompanied by a nonluminous **halo** mass. Galaxy dynamics indicate that there may be five to ten times more dark matter than luminous matter. Note in Table 1 that the average mass of a galaxy as determined by dynamical analysis is ten times that found for the visible mass only. This pushes the estimate of density in galaxies up to about 10 to 20 percent of the critical value.

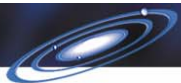
Mass-to-luminosity ratios are used to measure the amount of dark matter present. If  $M/L < 1$ , this implies the existence of dark matter, because there is mass there which cannot be accounted for by the small amount of light being emitted. If  $M/L = 1$ , this means that all of the mass is accounted for by the light being given off.

The mass/luminosity ratios for cosmic structures from galaxies to local superclusters are shown in the third column of Table 1. These increasingly large ratios show that the larger the piece of the universe sampled, the greater that percentage of dark matter found. But even the largest value for  $\Omega$  for superclusters is, at most, 30% of the critical mass density.

Table 1. Some values of  $\Omega$  for some dynamical cosmic structure systems

System	Mass (In units of solar mass)	M/L (mass/luminosity)	$\Omega$
Visible Galaxy	$10^9 - 10^{11}$	2	0.002
<b>Dynamical analysis</b>			
Galaxy	$10^{10} - 10^{12}$	10	0.01 - 0.02
Group	$10^{13}$	150	0.15
Cluster	$10^{14}$	250	0.25
Local Supercluster	$10^{15}$	300	0.15 - 0.3

Adapted from Rubin, Bright Galaxies, Dark Matter, p. 124.



There is increasing evidence of the presence of a large amount of dark, undetected matter “out there” that could vastly enhance the average density of the universe, but how much dark matter is there? Is there enough to make our universe flat or closed in the future, or will it remain open?