9.9: The Cosmos

> *a final crunch?*

The more distant quasars and galaxies are, the greater the speed with which they are observed to be receding from us. This expansion argues that somewhere between ten and twenty billion years ago the universe began with a big bang, a time before which there was no time.

We see around us relics of the big bang, not only today’s rapidly receding galaxies but also today’s abundance of the chemical elements-some among them still radioactive, the "still warm ashes of creation" (V. F. Weisskopf) - and today’s greatly cooled but still all-pervasive "primordial cosmic fireball radiation." We now believe that in the first instants of its life, the entire universe filled an infinitesimally small space of enormous density and temperature where matter and energy fused in a homogeneous soup. Immediately the universe began expanding. After about 10^{-6} seconds it had cooled enough that subatomic particles condensed from the matter-energy soup. In the first three minutes after the big bang, neutrons and protons combined to make heavier elements. Eons later stars and galaxies formed. Never since has the universe paused in its continual spread outward.

“ Open ”universe expanding forever? Or “closed” universe that recontracts to crunch? An open question!

Will the universe continue expanding forever? Or will its expansion slow, halt, and turn to contraction and crunch (Table $9.9.1$), a crunch similar in character but on a far larger scale than what happens in the formation of a black hole? Great question! No one who cares deeply about this question can fail to celebrate each week that week’s astrophysical advances: instruments, observations, conclusions.

We have come to the end of our journey. We have seen gravity turned to float, space and time meld into spacetime, and spacetime transformed from stage to actor. We have examined how spacetime grips mass, telling it how to move, and how mass grips spacetime, telling it how to curve. Of all the indications that existence at bottom has a simplicity beyond anything we imagine today, there is none more inspiring than the unsurpassed simplicity of gravity as we now see it.

References

Extended portions of this chapter were copied (and sometimes modified) from John Archibald W h e e l e r , Into Gravity and Spacetime (Scientific American Library, a division of HPHLP, New York, 1990).

For details of Galileo’s views on motion, see Galileo Galilei, Dialogues Concerning Two New Sciences, originally published March 1638; one modern translation is by Henry Crew and Alfonso de Salvio (Northwestern University Press, Evanston, 111., 1950).

How Newton came only in stages to the solution of the problem of fall is told nowhere with such care for the fascinating documentation as in Alexander Koyre, “A Documentary History of the Problem of Fall from Kepler to Newton,” Transactions of the American Philosophical Society, Volume 45, Part 4 (1955).

Keynes quotation under Newton portrait: Reprinted by permission of the publisher, Horizon Press, from Essays in Biography by John Maynard Keynes, copyright 1951.

For an exciting and readable overview of the experimental proofs of Einstein’s general relarivity theory, see Clifford M. Will, Was Einstein Right? Putting General Relativity to the Test (Basic Books, New York, 1986). In particular (Chapter 10, pages 181-206), he describes at some length the emission of gravity waves by the binary pulsar system studied by Joseph H. Taylor, Jr., and Russell A. Hulse.

Table $9.9.1$: A CLOSED-MODEL UNIVERSE COMPATIBLE WITH OBSERVATION

Radius at phase of maximum expansion	18.9×10^9 light-years or 1.79×10^{26} meters
Time from start to maximum size	29.8×10^9 years or 2.82×10^{26} meters
Radius today	13.2×10^9 light-years
Time from start to today’s size	10.0×10^9 years

Time it would have taken from start to today's size if the entire expansion had occurred at today's slowed rate of expansion	20.0×10^{9} years
Present expansion rate	An extra increment of recession velocity of 15.0 kilometers/second for every extra million light-years of remoteness of the galactic cluster
Fraction of the way around the 3- sphere universe from which we can in principle receive light today	$\frac{113.2 \text{ degrees}}{180 \text{ degrees}}=62.9\%$
Fraction of the matter in the 3-sphere universe that has been able to communicate with us so far	74.4%
Number of new galaxies that come into view on average every three days	One!
Average mass density today	$14.8 \times 10^{-27} \text{kilogram/meter}^3$
Average mass density at phase of maximum expansion	$5.0 \times 10^{-27} \text{kilogram/meter}^3$
Rate of increase of volume today	1.82×10^{62} meters^3/second
Amount of mass	$M_{\text{conv}}=5.68 \times 10^{53} \text{kilograms}$ In geometric units: $M=GM_{\text{conv}}/c^2=4.21 \times 10^{26}$ meters
Equivalent number of suns like ours	2.86×10^{23}
Equivalent number of galaxies like ours	1.6×10^{12}
Equivalent number of baryons (neutrons and protons)	3.39×10^{80}
Total time, big bang to big crunch	\(59.529 \times 10^{9} \text{ years) \)