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History of Astronomy: The Expanding Universe

How the Sky Began to Grow

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Introduction

The story of the expanding universe is the story of the single most surprising fact humanity has ever learned about its home: the sky is not a fixed backdrop with lights pinned to it, but a thing that grows. Every generation of astronomers before the twentieth century assumed, when it thought about the question at all, that the universe as a whole was steady, that the stars and the nebulae had always been where they are, in a cosmos either eternal and unchanging or bounded by a crystal sphere. Between 1912 and 1931 that assumption died, and it died fast, in the span of one working lifetime, killed by a handful of spectrographs, a Belgian priest with a physics degree, a Russian meteorologist with a talent for mathematics, and an American lawyer turned astronomer with access to the world's largest telescope.

This volume tells that story as a history of astronomy: what was believed before, what was observed, what was argued, and what the expansion came to mean for everything after. The discovery did not arrive as a single moment, and the honest account resists the textbook shortcut. The pieces came in from different directions over two decades. Vesto Slipher, at Lowell Observatory in Arizona, measured the first shifts in the light of the spiral nebulae starting in 1912 and found, to his own surprise, that almost all of them were fleeing the Milky Way at speeds no star had ever shown.

Alexander Friedmann, a meteorologist in Saint Petersburg, showed in 1922 that Albert Einstein's own theory of gravity permitted a universe that swells or shrinks, an idea Einstein himself had locked out with a patch to his equations. Georges Lemaitre, a Belgian physicist and priest, derived the same result independently in 1927, connected it to the receding nebulae, and proposed that the universe began as a single primeval atom. And Edwin Hubble, working with Milton Humason at Mount Wilson above Los Angeles, put the velocity and the distance together in 1929 and published the relation the world now calls the Hubble law: the farther a galaxy is from us, the faster it recedes.

The law's meaning took longer to settle than its publication. An expanding universe implied a beginning, and a beginning was an unwelcome thought to many of the era's finest physicists, Fred Hoyle among them, who built a rival theory, the steady state, precisely to keep the cosmos eternal. Hoyle, in a 1949 BBC broadcast, coined a mocking name for the theory he disliked, the Big Bang, and the nickname stuck to the thing it was meant to bury. The debate between the two pictures ran for decades and was settled not by argument but by evidence: the cosmic microwave background, found in 1965, carried the fingerprint of a hot dense beginning that the steady state could not explain.

The story did not end with the victory of the Big Bang picture, because the expansion itself had a surprise left. In 1998 two teams measuring distant supernovae found that the expansion is not slowing, as every expectation held, but speeding up, pushed by something now called dark energy that makes up most of the universe and that no theory yet explains. The discovery of the expansion, a century old in outline, is thus still unfinished: the question it opened, what the expansion is doing and where it will end, is the central problem of cosmology today.

The chapters that follow move through the discovery and its meaning: the old static universe and Einstein's reluctant constant; Slipher's spectra and Friedmann's mathematics; Lemaitre's primeval atom and Hubble's law; the great debate with the steady state school; the physics of the scale factor and the expanding space; the observations that measure the growth, from redshift surveys to the microwave background satellites; the acceleration and dark energy; the fates the expansion allows, from the Big Chill to the Big Rip; and the modern program of measuring the universe's growth with satellites and supercomputers. The account closes with the open questions, because the expanding universe is one of those rare subjects where the history is still being written by the people working on it now.

A preliminary observation belongs before the narrative starts, about the word discovery itself. The expanding universe is a case study in the philosophy of the word, since there was no single moment at which the fact became visible, and the priority disputes that follow any great finding are here unusually sharp and unusually settled at once. Friedmann published first, in 1922, and died before the observations; Lemaitre published the complete theory, in 1927, in a journal nobody read; Hubble published the observations, in 1929, in a journal everybody read, with a sentence crediting neither mathematician; and the modern resolution, the renaming of the law for two men in 2018, was the profession's way of saying what the documents had said all along, that the discovery was a relay, run by four people in three countries in two languages, and the runner with the baton at the finish line was not the only one who ran. The chapters ahead name each runner, and the naming is the history's own.

Chapter 1: The Discovery of The Expanding Universe

The discovery begins with a problem the nineteenth century did not know it had. The nebulae, the faint smudges catalogued by William Herschel and later by his son John and by the French comet hunter Charles Messier, were of unknown nature. Some were resolved into star clusters with bigger telescopes; some, like the Orion nebula, were clearly clouds of gas; but the spiral nebulae, the pinwheels first seen in detail by Lord Rosse in Ireland in the 1840s, stayed stubbornly unresolved, and the question of whether they were small nearby objects or vast distant systems, the island universes the philosopher Immanuel Kant had speculated about, remained open for seventy years.

The tool that would resolve the question was the spectrograph, which spreads a star's light into its colors and reads from the pattern both the chemistry of the source and its motion. The principle is the Doppler shift, familiar from the way a train whistle drops in pitch as it passes: light from a source moving away is stretched to longer, redder wavelengths, and light from an approaching source is compressed to bluer ones. The shift in the spectral lines, measured against laboratory standards, gives the velocity along the line of sight. By the 1910s the technique was routine for the stars, and the obvious next step was to point it at the nebulae.

The man who took the step was Vesto Slipher, a young spectroscopist at Percival Lowell's observatory in Flagstaff, Arizona. Lowell had built the institution to study Mars, and Slipher was set to work on the planets, but the observatory's new spectrograph, a fast instrument built for faint light, was capable of something more ambitious, and around 1910 Slipher began exposing it on the spiral nebulae, which are among the faintest objects in the sky. The work was brutal: a single usable spectrum of a nebula could require exposures spread over many nights, hours of a telescope's time each, for an object whose total light is a small fraction of a bright star's. In late 1912 Slipher obtained the spectrum of the Andromeda nebula, the largest spiral in the northern sky, and found it blueshifted, approaching at some 300 kilometers per second, a velocity far beyond any star's, but at least in the expected family of motions.

Then the other spirals came in, and the result stopped making sense in the old way. By 1917 Slipher had measured more than twenty of them, and almost all were redshifted, receding, at velocities past a thousand kilometers per second, the largest of any known objects. There was no way to arrange this in the standard picture, in which the nebulae were a local family of objects in a static

universe: a static universe has no reason for everything on one side of the sky to be running away from us. Slipher, cautious as he was, said as much in his reports, noting that the velocities were the largest of any known objects and that the preponderance of redshifts suggested a general recession. The Dutch astronomer Willem de Sitter heard of the work and built a theoretical model, published in 1917, in which a universe governed by Einstein's new theory of gravity showed exactly such an effect, and the strange redshifts became, for the first time, a cosmological datum.

Meanwhile the mathematics was moving ahead of the observations, in two places at once. Einstein, having completed his theory of general relativity in 1915, applied it to the universe in 1917 and found to his discomfort that his own equations refused to describe a static cosmos: gravity pulled, and something had to balance it. His fix was the cosmological constant, a term added to the equations to hold the universe still, a term he would later call the greatest blunder of his life. That same year de Sitter found another solution, an apparently empty universe that nonetheless predicted a redshift increasing with distance, which gave the theorists something to argue about while the observers caught up.

The argument arrived from an unexpected quarter. Alexander Friedmann was a meteorologist and mathematician in Saint Petersburg, a balloonist who had calculated bomb trajectories for the Russian air service and run an aerodynamics observatory; cosmology was his side work. In 1922 he published a paper that stepped past both Einstein's and de Sitter's solutions, showing that the equations of general relativity admitted a whole family of universes that expand or contract with time, and that the static case was just one special, unstable member of the family. Einstein, prompted by a colleague, at first claimed to have found an error, then on a second reading conceded that the criticism did not hold; the correction, printed in 1923, is a two line note that quietly reopened the universe. Friedmann died of typhoid in 1925, never learning that the real sky had chosen one of his models. His book, written for lay readers and published posthumously, imagined the universe as a soap bubble that might swell from a point.

The synthesis came from Georges Lemaitre, a Belgian who held two careers at once, an ordained priest and a physicist, who had studied at Cambridge with Arthur Eddington and at the Massachusetts Institute of Technology, and who in 1927 published, in an obscure Brussels journal, a paper that did everything at once. Lemaitre took

Friedmann's mathematics, connected it to Slipher's redshifts, and derived from it the linear relation between distance and velocity that would make the

expansion visible. He noted, correctly, that the whole thing followed from general relativity, and that the cosmic redshift was not a Doppler effect through space but the stretching of light by the growth of space itself, and he gave a value for the rate of expansion two years before Hubble's announcement. The paper sank without trace, because it was in French, in a minor journal, from a country with no school of cosmology, and because the astronomical world was not ready to hear it.

What the world was ready to hear, in 1929, was the same result with the name Edwin Hubble attached, backed by the data of the 100 inch Hooker telescope, the largest on earth, on Mount Wilson above Los Angeles. Hubble, a lawyer turned astronomer with a talent for the decisive measurement, had spent the 1920s doing two things: proving that the spiral nebulae were galaxies outside the Milky Way, using Cepheid variable stars as distance markers, and collecting, with his assistant Milton Humason, the velocities Slipher's program had begun and others had extended. In 1929 he published the relation: velocity proportional to distance, the farther galaxies receding faster, at a rate of roughly 500 kilometers per second per megaparsec. The number was wrong by a factor of several, the calibration of the era being crude, but the proportionality, the fact on which everything after rests, was in the table for anyone to read.

The aftermath is part of the discovery too. At the 1927 Solvay conference and after, Einstein, shown Lemaitre's work, at first resisted and then yielded, dropping the cosmological constant and accepting the expanding solution as physical reality rather than a mathematical curiosity. In 1931, invited to speak about the beginning of the universe, Lemaitre proposed that the expansion, run backward, implied a beginning, a primeval atom, a day without a yesterday, the first statement of what would become Big Bang cosmology. Hubble himself, cautious to the end, described his result in observational terms and declined to commit publicly to the expanding space interpretation, though privately he accepted it. Within five years the static universe, the assumption of every astronomer since the invention of the telescope, was gone, and the profession had replaced it with a cosmos that had a history: an age, an origin, and a future, all of which could be measured.

A closing observation about the chapter's subject, for the reader who wants the discovery in one sentence: the expanding universe was discovered three times, in the mathematics of Friedmann in 1922, in the mathematics and physics of Lemaitre in 1927, and in the observations published by Hubble in 1929, and the discovery was complete only when the three were joined, a fact the International Astronomical Union recognized in 2018 by renaming the law the Hubble Lemaitre law, eighty nine years after the fact, correcting the record

in the direction of the evidence. Something should be said about how the professionals picture the growth, since the bread dough and the balloon analogies of the popular books are both wrong in instructive ways.

The working picture is the coordinate grid, drawn on a rubber sheet: the galaxies sit at fixed grid points, and the grid itself stretches, and the proper distance between any two points is the grid coordinate times the scale factor, which is the whole of the FLRW bookkeeping in one sentence. The balloon analogy fails because the universe is not a surface, and it fails more deeply because the balloon grows into the room around it, which the universe does not, there being no room around it, and the raisin dough fails because the dough has an edge, which the universe may not have.

The honest popular statement, and the one this book keeps, is that the distances grow, the galaxies do not fly, and every picture that makes the growth look like a motion through a preexisting space is a picture the mathematics does not license, and the reader who internalizes the grid is holding the same picture the cosmologists hold.

End of free sample. The full book is available at putrabooks.github.io

ABOUT THE AUTHOR

Aira Astralis is a science writer specializing in astronomy and space exploration. Her work spans the full breadth of humanity's relationship with the cosmos -- from the earliest naked-eye observations to the engineering marvels of modern space missions.

Her books are built on a foundation of primary sources: peer-reviewed research, mission archives, and direct engagement with the scientific community. She writes for readers who want to understand not just what we know about the universe, but how we came to know it.

She believes that the most important frontier is not out there but in the gap between what scientists discover and what the public understands. Her books exist to close that gap.