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IS THE UNIVERSE EXPANDING?: AN HISTORICAL AND PHILOSOPHICAL  
PERSPECTIVE FOR COSMOLOGISTS STARTING ANEW

by

David A. Vlosak

A Thesis  
Submitted to the  
Faculty of The Graduate College  
in partial fulfillment of the  
requirements for the  
Degree of Master of Arts  
Department of Philosophy

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# IS THE UNIVERSE EXPANDING?: AN HISTORICAL AND PHILOSOPHICAL PERSPECTIVE FOR COSMOLOGISTS STARTING ANEW

David A. Vlosak, M.A.

Western Michigan University, 1996

This study addresses the problem of how scientists ought to go about resolving the current crisis in big bang cosmology. Although this problem can be addressed by scientists themselves at the level of their own practice, this study addresses it at the meta-level by using the resources offered by philosophy of science.

There are two ways to resolve the current crisis. Either cosmologists can continue working on big bang theory or they can start anew. For those who choose to start anew, this study argues it would be a mistake for them to assume any new cosmological theory would have to explain expansion rather than nonexpansion of the universe. This does not mean expansion theory should be excluded or that nonexpansion theory is to be preferred. Rather, this means that cosmologists may have another option in addition to expansion theory and that nonexpansion theory should not be automatically excluded.

Over a century of relevant scientific developments as well as the reasons involving spectral redshifts used to change from static to expansion cosmological theory in the 1930s is discussed. In addition, eight redshift theories are examined.

## ACKNOWLEDGMENTS

A person's life can be characterized as the "process of becoming" - a process that is never completed but always ongoing. Throughout this process, certain people provide perspectives, insights, and guidance which prove to be beneficial. The following are just a few who have contributed to my "becoming."

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David A. Vlosak

## TABLE OF CONTENTS

ACKNOWLEDGMENTS .....	ii
CHAPTER	
I. INTRODUCTION .....	1
Problem Statement .....	1
Overview .....	3
II. A CURRENT CRESCENDOING COSMOLOGY CRISIS .....	5
Current Discrepancies Between the Age of the Universe and the Age of Stars .....	6
Inhomogeneity-Anisotropy Observations .....	9
The Great Wall .....	11
The Great Attractor .....	11
Pencil Beam Surveys .....	13
Supervoids .....	13
The Lauer-Postman Studies .....	14
Galaxy Formation Impossibilities .....	15
Quantization Contraindication .....	19
III. THE SHIFT FROM STATIC TO RELATIVISTIC-EXPANSION COSMOLOGICAL THEORY .....	22
Spectral Redshifts and an Optical-Doppler Redshift Theory .....	23

## Table of Contents--Continued

### CHAPTER

Overview . . . . .	23
History . . . . .	23
Evaluation . . . . .	36
Relativity Theory, an Optical-Doppler Redshift Theory, a Redshift-Distance Relation, and Nonexpansion Cosmological Theory . . . . .	37
Overview . . . . .	37
History . . . . .	38
Evaluation . . . . .	49
Relativistic-Expansion Cosmological Theory, a Redshift-distance Relation, and a Space-Expansion Redshift Theory . . . . .	50
Overview . . . . .	50
History . . . . .	50
Evaluation . . . . .	60
Conclusion . . . . .	62
IV. REDSHIFT-DISTANCE DIFFICULTIES, HUBBLE LAW INVALIDATION, AND ALTERNATIVE REDSHIFT THEORIES . . . . .	63
Current Reasons Cited for Assuming Expansion . . . . .	63
Good and Compelling Reasons? . . . . .	65
Redshift-Distance-Relation and Hubble Law Difficulties . . . . .	65
Six Alternative Redshift Theories . . . . .	81

## Table of Contents--Continued

### CHAPTER

Conclusion .....	99
<b>V. THEORETICAL VIRTUES .....</b>	<b>102</b>
Definition of "A Good and Compelling Reason" .....	102
Explanatory Power .....	103
Definition .....	103
The Intrinsic-Property Redshift Theory .....	103
The Compton Redshift Theory .....	104
The Interstellar-Medium Redshift Theory .....	104
The Light-Coherence Redshift Theory .....	104
The Transverse-Velocity Redshift Theory .....	105
The Gravitational Redshift Theory .....	106
The Optical-Doppler Redshift Theory .....	106
The Space-Expansion Redshift Theory .....	106
Conclusion .....	106
Predictive Power .....	107
Definition .....	107
The Intrinsic-Property Redshift Theory .....	107
The Compton Redshift Theory .....	107
The Interstellar-Medium Redshift Theory .....	107

## Table of Contents--Continued

### CHAPTER

The Light-Coherence Redshift Theory .....	108
The Transverse-Velocity Redshift Theory .....	108
Gravitational Redshift Theory .....	108
The Optical-Doppler Redshift Theory .....	109
The Space-Expansion Redshift Theory .....	109
Conclusion .....	109
Testability .....	109
Definition .....	109
Conclusion .....	110
Consistency .....	110
Definition .....	110
The Space-Expansion Redshift Theory .....	110
Conclusion .....	111
Circularity .....	111
Conclusion .....	112
VI. CONCLUSION .....	113
Summary .....	113
Conclusion .....	114

Table of Contents--Continued

**APPENDIX**

A. Background Cosmological Concepts . . . . .	115
<b>BIBLIOGRAPHY . . . . .</b>	<b>125</b>

## CHAPTER I

### INTRODUCTION

#### Problem Statement

There is currently a crisis in big bang cosmology. In this thesis I will address the problem of how scientists ought to go about resolving this crisis.

This problem can be addressed at more than one level. Certainly, it can be addressed by scientists themselves at the level of their own practice. My purpose, however, is to address this problem at the meta-level by using the resources offered by philosophy of science.

My plan is to draw on Thomas Kuhn's insights into the process of scientific inquiry. Kuhn observes that this process can involve a pattern of normal science - anomaly - crisis - resolution - normal science. For instance, under an accepted and relatively successful body of theory, scientists engage in what Kuhn calls "normal science," which involves research aimed at articulating the theories and phenomena that are already supplied by the body of theory. During this research, anomalies often appear. After a time, if these anomalies are not accommodated by the existing body of theory, a growing crisis emerges. Usually the crisis is resolved by modifying or even changing the body of theory. Then scientists can once again engage in normal science. According to Kuhn, it is particularly in times of crisis that scientists turn to

philosophical analysis to assist in delineating and examining assumptions as well as to find a solution.

Given the current situation, then, there are two ways to resolve the current crisis in big bang theory. Either cosmologists can continue working on big bang theory, as they have been doing for some time, or they can start anew. For those who choose to start anew, I will argue it would be a mistake for them to assume any new cosmological theory would have to explain expansion rather than nonexpansion of the universe.

Scientists might be somewhat startled by this claim, especially since expansion has been taken for granted for decades. In fact, there probably will be resistance to such a proposal, as Kuhn himself would no doubt expect. But I will show through a critical analysis that although the acceptance of expansion theory made sense in the 1930s, there no longer are good and compelling reasons to assume expansion today. Recognizing such an unwarranted assumption is the advantage of addressing this problem at the meta-level. As a philosopher, a perspective can be considered that a scientist might not think of considering or even be able to consider due to the parameters of the current scientific body of theory.

## Overview

This study is organized in the following manner. Chapter II denotes the current crisis in big bang theory due to some of its problematic discrepancies with observational data.

Chapter III examines historically the reasons for abandoning in the early 1930s a static universe theory and accepting an expansion one. This change was fundamentally due to spectral-redshift observational data that was interpreted first as optical-Doppler and then space-expansion effects. It is concluded that given the redshift theories and observational data available by the early 1930s, cosmologists had good compelling reasons for making the change to an expansion cosmological theory.

Chapter IV notes difficulties with the redshift-distance relation and the invalidation of the Hubble law. Although the redshift-distance relation is still considered presently valid, it requires the application of the space-expansion redshift theory to be used as evidence for an expanding universe. Therefore, six alternative redshift theories in addition to Doppler and space-expansion redshift theories are presented in order to determine in the next chapter whether there are any good and compelling reasons to assume space-expansion redshift theory rather than some other redshift theory.

Chapter V analyzes the six alternative redshift theories as well as the Doppler and space-expansion theories in terms of the following four truth-conducive theory virtues: (1) explanatory power, (2) predictive power, (3) testability, and (4)

consistency. In particular, it is concluded that none of these theories are presently disconfirmed. Furthermore, all eight redshift theories are consistent with both expansion and nonexpansion theory of the universe - except for space-expansion redshift theory, which is inconsistent with nonexpansion theory. However, this redshift theory is circular with reference to expansion theory. It is concluded there are no good and compelling reasons to assume space-expansion redshift theory rather than some other redshift theory.

Chapter VI summarizes this study and concludes that this study's thesis has been supported, which states that if some cosmologists start anew, it would be a mistake for them to assume that any new cosmological theory would have to explain expansion rather than nonexpansion of the universe.

In addition, a review of relevant scientific concepts foundational to this study is provided in the Appendix. Also, a topical bibliography is provided for further study.

## CHAPTER II

### A CURRENT CRESCENDOING COSMOLOGY CRISIS

In the preceding chapter, it was claimed that a current crisis in contemporary cosmology exists. Since no support for this claim was provided, some cosmologists might disagree with this assertion and, consequently, see no need to even consider starting anew, much less not assume expansion rather than nonexpansion of the universe. In other words, as the old adage says, "If it isn't broke, why fix it?" Therefore, it seems worthwhile to explore the basis for the preceding chapter's claim in at least two ways.

First, whether or not there is an actual crisis in current cosmology, some cosmologists and science writers perceive there is one. In recent years, this perception has increased as is evinced by the growing number of published articles with titles as the following: "Crisis In the Cosmos," "Unraveling Universe," "Cosmology: All Sewn Up or Coming Apart at the Seams?" "The Universe in Crisis," "The Age Paradox," "The Hubble Inconstant," "More Muddle Over the Hubble Constant," and "Dark Doubts For Cosmology."

This perception of a cosmological crisis alone is sufficient to warrant this study's thesis' caveat. For whether or not there is an actual crisis, such a perception may lead some cosmologists to start anew. And if they start anew, given that there no

longer are any good and compelling reasons to assume expansion rather than nonexpansion (as it will be later argued), it would be a mistake for them to make such an assumption.

Second, however, there does appear to be evidence that an actual crisis exists. Although several problems could be pointed out, four significant ones will be discussed: (1) current discrepancies between the age of the universe and the age of stars, (2) inhomogeneity-anisotropy observations, (3) galaxy formation impossibilities, and (4) quantization contraindication.

#### Current Discrepancies Between the Age of the Universe and the Age of Stars

Many astronomers have found that the Hubble constant is around 80. This value implies that the universe is only 8 to 11 billion years old, younger than the estimated ages of the oldest stars. Clearly, something is wrong: either the age of the universe or the age of those stars - or, just possibly, modern cosmology itself.<sup>1</sup>

The majority of recent studies by groups of prominent astronomers have estimated Hubble constant<sup>2</sup> values that translate into young ages for the universe. Perhaps the most prestigious group, which has been awarded a large chunk of continuous time on the Hubble Space Telescope, is headed by Wendy Freedman. Freedman's estimated Hubble constant of about  $80 \pm 17 \text{ km s}^{-1} \text{ Mpc}^{-1}$ , extending out to a distance of about 100 Mpc, translates into an age of the universe of about 8 billion

<sup>1</sup> Ken Croswell, "A Milestone in Fornax," Astronomy (October 1995): 43.

<sup>2</sup> The Hubble constant indicates the rate of the universe's expansion.

years.<sup>3</sup> Data from the Canada-France-Hawaii Telescope, headed by Michael J. Pierce, gives an age of the universe between 7 and 11 billion years, with 7 billion most likely.<sup>4</sup> N.R. Tanvir's 1995 research led him to estimate the age of the universe between 9 and 11 billion years.<sup>5</sup>

By contrast, the oldest stars in the Milky Way Galaxy are estimated to range in age between 14 and 19+ billion years old.<sup>6</sup> Ray Jayawardhana also reports on groups of astronomers who age globular clusters of stars around 19 billion years old. Sam Flamsteed comments:

The oldest stars, some cosmologists claim hopefully, might just be able to squeeze into a 14-billion-year-old universe - but the chances are slim. The stars are probably older than that. "We are really happier with 17," says Pierre Demarque, a stellar evolution theorist at Yale. "The cosmologists are constantly pressuring us to stretch this a little further, but believe me, we can't. And our group consistently gets

<sup>3</sup> Wendy L. Freedman, Barry F. Madore, Jeremy R. Mould, Robert Hill and others, "Distance to the Virgo Cluster Galaxy M100 from Hubble Space Telescope Observations of Cepheids," Nature 371 (27 October 1994): 761.

<sup>4</sup> Michael J. Pierce, Douglas L. Welch, Robert D. McClure and others, "The Hubble Constant and Virgo Cluster Distance from Observations of Cepheid Variables," Nature 371 (29 September 1994): 389; Sharon Begley, "The Cosmic Dating Game," U.S. News & World Report (7 November 1994): 13; Craig J. Hogan, "Cosmological Conflict," Nature 371 (29 September 1994): 374-75.

<sup>5</sup> N.R. Tanvir, T. Shanks, H. C. Ferguson and D. R. Robinson, "Determination of the Hubble Constant from Observations of Cepheid Variables in the Galaxy M96," Nature 377 (7 September 1995): 27.

<sup>6</sup> Sam Flamsteed, "Crisis in the Cosmos," Discover (March 1995): 72; Ken Croswell, Astronomy, 1995, 42; N. R. Tanvir, 1995, Nature, 27; Joshua Roth and Joel R. Primack, "Cosmology: All Sewn Up or Coming Apart at the Seams?" Sky & Telescope (January 1996): 20.

younger ages for the stars than most others do. The stars could easily be as old as 19 or 20 billion years, or even older."<sup>7</sup>

Furthermore, according to John Gribbin, astrophysicist and author of In Search of the Big Bang, our Milky Way galaxy formed when the universe was half its present age.<sup>8</sup>

Therefore, if the globular clusters of stars are 15 billion years old, the universe would have to be over 30 billion years old. And in galaxies older than the Milky Way, the stars would have to be accordingly older than Milky Way stars.

Although more could be said concerning this discrepancy between the age of the universe and stars, two representative quotations expressing the serious implications of this problem for big bang theory are provided below:

No one ever thought it would come to this. No one ever thought the Milky Way Galaxy might topple the big bang. Large though the Milky Way is, it is just one galaxy in a universe tens of billions of light-years wide. But today, a disturbing specter haunts astronomy: the galaxy may be older than the universe, a logical contradiction that could demolish standard cosmology."<sup>9</sup>

And:

Is there a crisis in cosmology, or is it that the latest measurement of the Hubble constant is yet another of those numerical disagreements that plague the field from time to time? . . . the Hubble constant implies an age of the Universe much smaller than the known ages of the stars in globular clusters in our Galaxy. The obvious question is how that can

<sup>7</sup> Sam Flamsteed, Discover, 72.

<sup>8</sup> John Gribbin, In Search of the Big Bang: Quantum Physics and Cosmology (New York: Bantam Books, 1986): 212.

<sup>9</sup> Ken Croswell, The Alchemy of the Heavens (New York: Doubleday, 1995): 230.

be if the stars in the Galaxy were formed within the lifetime of the Universe. The obvious answer is that the result, the third of its kind in under a year, makes a nonsense of the standard Big Bang view of how the Universe began.<sup>10</sup>

### Inhomogeneity-Anisotropy Observations

From its inception, big bang theory has required the universe to be both homogenous (i.e., possess uniformity such as in overall structure, medium, process, motion, and in particular the even distribution of mass at the level of the largest-scale structures currently called superclusters) and isotropic (i.e., appear indistinguishable in all directions to an observer expanding with the universe).

For example, Steven Weinberg's big bang landmark book The First Three Minutes repeatedly emphasizes these requirements, although he allows for local or peculiar motions, such as orbital and rotational motions, to be inconsistent with the overall perfectly-even expanding motion of typical galaxies, which are simply carried along with the general cosmic expansion flow. This uniform expansion motion is called the Hubble flow.

Recent studies of large-scale structure and motion, however, have revealed that "a billion light-years worth of matter is sliding sideways across the universe," which contradicts Weinberg's above "qualification."<sup>11</sup> Though estimates of exact

<sup>10</sup> John Maddox, "Big Bang Not Yet Dead But in Decline," Nature 377 (14 September 1995): 99.

<sup>11</sup> Flamsteed, 1995, Discover, 72.

distances, directions, and speeds vary somewhat, it can safely be summarized that inhomogeneity and anisotropy of structure, motion, and apparent rates of space expansion have been demonstrated out to the very edges of the observable universe.

Even before the latest studies (i.e., Lauer-Postman), Helge Kragh wrote:

. . . large-scale inhomogeneities observed in the 1980s seem to indicate a structural universe which may contradict one of the foundations of big bang cosmology, the uniformity postulate (or cosmological principle). This and other problems have recently caused some cosmologists to declare the big bang theory in a state of crisis.<sup>12</sup>

Paul Hodge adds that "although the universe was at first assumed to be expanding uniformly, the wholesale use of the Tully-Fisher relation revealed departures from uniformity."<sup>13</sup>

The major studies which have demonstrated inhomogeneity and anisotropy include: (a) The Great Wall (1986-9), (b) The Great Attractor (ongoing since 1986), (c) The Pencil Beam Surveys (ongoing since the 1980s), (d) Supervoid Studies (1981-95), and most importantly (e) The Lauer-Postman Studies (ongoing since 1989). These studies will be briefly discussed.<sup>14</sup>

<sup>12</sup> Helge Kragh, "Big Bang Cosmology," in Encyclopedia of Cosmology: Historical, Philosophical, and Scientific Foundations of Modern Cosmology, ed. Norriss Hetherington (New York: Garland Publishing, Inc., 1993), 41.

<sup>13</sup> Paul Hodge, "The Extragalactic Distance Scale: Agreement at Last?" Sky & Telescope (October 1993): 19.

<sup>14</sup> For the reader interested in further research of these topics, a few representative studies are included in this study's topical bibliography. Also, some computer-search descriptors include streaming, large-scale structure, large-scale motion, superclusters, supervoids, Great Wall, Great Attractor, Pencil Beam and galaxy surveys, and cosmic velocity fields. Authors include Margaret Geller, John Huchra,

### The Great Wall

The Great Wall is a sheet of galaxies 500 million light-years long, 200 million light-years wide, and 15 million light-years thick. It probably extends beyond the boundaries surveyed so far. The Great Wall discovery by Margaret Geller of the Harvard-Smithsonian Center for Astrophysics contradicts the homogeneity claimed by big bang theory.

### The Great Attractor

The Great Attractor is some distant point (perhaps a collection of galaxy clusters) in the direction of the constellations Hydra and Centaurus toward which galaxy clusters are streaming out to a distance of at least 60 megaparsecs at a velocity of about 400 kilometers per second.

But more surprising is the findings of Australian astronomer Donald Mathewson and his colleagues from the Mount Stromlo Observatory in Australia. Not only did they discover galaxies beyond the Great Attractor moving in the same direction as the galaxies on this side of it, but "The Great Attractor itself seems to be moving downstream."<sup>15</sup> Cosmologists have mapped this flow as far as galaxy motions

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Alan Dressler, Sandra Faber, Donald Lynden-Bell, David Burstein, Thomas Broadhurst, Richard Ellis, David Koo, Ulrich Lindner, Tod Lauer, and Marc Postman.

<sup>15</sup> Ann Finkbeiner, "Mapping the River in the Sky," Science 257 (28 August 1992): 1209.

can be measured, but its extent is still unknown. The Great Attractor and its accompanying streaming galaxy clusters are inconsistent with big bang theory's claim of homogeneous and uniform motion.

The group of astronomers most credited with finding The Great Attractor was called the "Seven Samurai." Some of them have further studied The Great Attractor and decided it is falling into the "Shapley Concentration," which appears to be a larger and more distant attraction.<sup>16</sup>

Neither the overall flow stretching over Northern and Southern skies nor its discrepant sub-flows can be accounted for by correcting for peculiar motions. In 1990, Alan Dressler and Sandra Faber reviewed previous large-scale streaming studies and did further research. They found no flaw in the Seven Samurai's data and concluded the total data was inconsistent with any model of galaxy formation and with models based on hot or cold dark matter. Furthermore, the end of the discrepancy between the streaming-motion data and the expected "Hubble diagram" was not found, though the volume of space studied was about  $100 h^{-1}$  Mpc in diameter.<sup>17</sup>

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<sup>16</sup> Michael D. Lemonick, The Light at the Edge of the Universe (Princeton, N. J.: Princeton University Press, 1993), 15.

<sup>17</sup> Alan Dressler, and S. M. Faber, "New Measurements of Distance to Spirals in the Great Attractor: Further Confirmation of the Large-scale Flow," Astrophysical Journal 354 (10 May 1990): L48.

### Pencil Beam Surveys

Pencil Beam surveys investigate an extremely narrow beam of space, which is very long, thin, cone-shaped, and extends from earth out to approximately 2000 Mpc. Beams taken through North and South Galactic Poles show periodic oscillations of density with distance. In other words, structures like The Great Wall appear periodically spaced about 128 Mpc apart. Margaret Geller writes, "The more distant peaks may well be other great walls about 300 to 400 million light-years apart...."<sup>18</sup> Pencil Beam surveys in other directions, however, show no periodicity, which calls into question the isotropy-homogeneity of the universe. It should also be noted that the periodic oscillations are considered inhomogenous and anisotropic, even if regularly spaced.

### Supervoids

Supervoids have been found throughout space between galaxy clusters. Some of these voids are hundreds of millions of light-years in diameter. Furthermore, they are hierarchical,<sup>19</sup> irregular, and complex. This also seems to indicate an anisotropic-inhomogenous universe.

<sup>18</sup> Margaret J. Geller and John P. Huchra, "Mapping the Universe," Sky & Telescope 82 (August 1991): 138.

<sup>19</sup> This hierarchy is categorized as supervoids, parent voids, children voids, and subvoids.

## The Lauer-Postman Studies

The Lauer-Postman studies were intended to find "convergence" - that is, the location where local or transverse or lateral streaming motion of galaxies ended and where the "pure Hubble flow" of uniformly expanding space began. At convergence, galaxies would no longer have gravitational influence on each other; therefore, expansion could occur.

Faye Flam summarizes the focus of these studies: "...galaxies in a huge chunk of the universe, a region at least one billion light-years across that includes our own Milky Way, appear to be moving, all in the same direction at about 435 miles per second, or 1.56 million miles per hour."<sup>20</sup> She also notes what the findings of these studies indicate according to Princeton theorist Bohdan Paczynski: "...it implies the existence of a universe that is uneven on scales far larger than theorists can explain with current models of structure formation...."<sup>21</sup>

Furthermore, in studying 119 galaxy clusters, researchers used the microwave background radiation as a stable, isotropic frame of reference, which is claimed to be their strongest evidence for an isotropic and homogenous universe. But even this claim is now being questioned.<sup>22</sup>

<sup>20</sup> Flamsteed, 1995, Discover, 66.

<sup>21</sup> Faye Flam, "Galaxies Keep Going with the Flow," Science 259 (1 January 1993): 31.

<sup>22</sup> Flam, F., 1993, Science, 31; August E. Evrard and Nick Kaiser, "A Sudden Squall in the Cosmos," Nature 368 (28 April 1994): 806-7.

Jeff Hecht reports that after all corrections were made, the studied galaxy clusters were found to be moving at an average speed of 690 km per second in a sideways direction rather than in radial velocities, which is incompatible with homogeneity and the expansion of the universe.<sup>23</sup> Sandra Faber, one of the original Seven Samauri who discovered The Great Attractor, says that no statistical fluke or other error can be found. Other astronomers also have closely investigated the data since 1992 and have not found errors. Even Margaret Geller, who is famous for 3-D maps of the universe, can find no error.

The findings threaten expansion models of the universe on the basis of inhomogeneity, anisotropy, and uneven expansion on the largest scales known. There also are incompatibilities with theories of galaxy formation.

Still, some cosmologists refuse to accept the observational data. As Lemonick points out: "No one can explain what Lauer and Postman might have done wrong, despite strenuous efforts to do so. The analysis is incorrect, they say, simply because it doesn't fit in with any existing theory of how the cosmos works."<sup>24</sup>

### Galaxy Formation Impossibilities

There are at least three major ways in which the formation of galaxies, galaxy clusters, and superclusters are incompatible with Big Bang Theory.

<sup>23</sup> Jeff Hecht, "What's Virgo's Big Attraction?" New Scientist 142 (18 June 1994): 19.

<sup>24</sup> Michael D. Lemonick and J. M. Nash, "Unraveling Universe," TIME (6 March 1995): 77.

First, galaxies have been found existing in locations "too far back in time" when they should not yet have formed.<sup>25</sup>

Second, there is no way or mechanism or process by which galaxies could have formed from the four forces within the parameters of the generally-accepted principles and processes of physics and chemistry.

For instance, the universe is supposed to have agglomerated or coalesced or formed gravitationally. Lemonick explains:

First came the Big Bang, an explosion of unimaginable violence, and power, in which the entire cosmos was born. Then, as the pure energy of the explosion expanded and cooled, and condensed from energy into matter, tiny regions of slightly higher density than average began to grow. Their gravity pulled in the surrounding matter, and they grew steadily larger until they formed the concentrations of mass that eventually became galaxies.<sup>26</sup>

But Margaret Geller of the Harvard-Smithsonian Center for Astrophysics, while commenting on her Great Wall discovery, stated that "no known force could produce a structure this big since the universe was formed."<sup>27</sup>

The problem is that gravity does not pull fleeing photons, particles, or atoms together, particularly not when they are already on trajectories leading them farther

<sup>25</sup> Lemonick, M. D., 1995, TIME, 78; John Horgan, "Universal Truths," Scientific American (December 1992): 115; Sky & Telescope, "News Notes," Sky & Telescope 76, no. 2 (August 1988): 124.

<sup>26</sup> Lemonick, Light at the Edge of the Universe, 12.

<sup>27</sup> Margaret Geller, quoted in Marmet, Paul, "The Cosmological Constant and the Red Shift of Quasars," IEEE Transactions on Plasma Science 20 (6 December 1992): 959.

and farther apart. Not even the suggested "cooling" makes nature break its presently understood patterns and constraints in this way. Gravity acts only negligibly on very small masses. Thus, the early formation of the initial cosmic structures are problematic to contemporary cosmology:

The development of cosmic structure - galaxies and their distribution - depends upon many poorly known or even unknown properties of the universe and its contents....both galaxies and clusters of galaxies are held together by the force of gravity. These large systems developed from smaller concentrations of matter in the early universe. But the origin and properties of the small lumps and bumps are puzzles we have yet to solve.<sup>28</sup>

Furthermore, in the early big bang scenario, gravity is supposed to act perfectly evenly. This should lead to a more "nonlumpy" universe than what observation indicates.

Big bang theory has for decades called for an absolutely uniform beginning and dispersion of mass and radiation. But this should have produced a sea of homogenous particles, which is not consistent with current observation. So big bang theorists have suggested many ideas for how some slight inhomogeneity or "perturbation" could have started the gravitational clumping of particles. However, Alan Guth, who is the creator and a proponent of inflationary theory, points out that since the standard big bang model provides no explanations for the etiology or form of such perturbations, "an entire spectrum of primordial perturbations must be assumed as part of the initial

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<sup>28</sup> Geller, Margaret and John P. Huchra, 1991, Sky & Telescope, 138.

conditions."<sup>29</sup> After looking to the new inflationary model to provide for early inhomogeneities, Guth notes that these inhomogeneities are not mathematically consistent with the observed cosmic microwave background. Furthermore, he adds that the grand unified theory, which offers these inhomogeneities, lacks credibility because of its falsified predictions about protons.<sup>30</sup> As a possible solution, Guth then suggests that these problems are surmountable by constructing "more complicated grand unified theories that result in density inhomogeneities of the desired magnitude (as well as a value for the proton life-time that is consistent with experiment)."<sup>31</sup> But then he acknowledges that this more complicated solution is inconsistent with the postulated and undiscovered Higgs boson, which is necessary to make inflation possible.

The third major incompatibility between big bang theory and large-structure formation is that there is too little time in the big bang scenario for galaxies and clusters to have formed gravitationally. "The remarkable smoothness of this [microwave background] radiation shows that...there is simply not time for gravity to have assembled the galaxies and clusters we see today."<sup>32</sup>

<sup>29</sup> Alan Guth, "Inflationary Universe," in Encyclopedia of Cosmology, ed. Hetherington, 308. See also the fourth question in Guth's list: "Questions Left Unanswered by the Standard Big Bang Theory," 306.

<sup>30</sup> Ibid., 611-2.

<sup>31</sup> Ibid., 612.

<sup>32</sup> Michael Rowan-Robinson, "Dark Doubts for Cosmology," New Scientist (9 March 1991): 30.

Flamsteed notes the serious revolutionary implications of this problem:

Too little mass, too little time - either problem alone would be disturbing. Taken together they raise the specter of a scientific revolution, a shift in the cosmological worldview in which some fundamental assumptions in cosmological theory - perhaps even the Big Bang itself - will have to give.<sup>33</sup>

### Quantization Contraindication

Respected University of Arizona astronomer William G. Tifft has discovered that galactic and quasar redshift<sup>34</sup> values fall only at certain fixed values and not in between. Thus, redshifts seem to have "preferred values," banding or bunching around multiples of approximately 72 km per second, including submultiples of 24 and 36-7 km per second. Therefore, they are said to be "quantized."

This quantization, however, seems to conflict with big bang theory. For instance, since the Hubble formula claims that redshifts increase proportionally with distance, then as the universe expands redshifts should increase accordingly. This means that redshifts would also have values in between multiples and submultiples of 72 km per second. But no significant amount of such intermediate redshift values are found. Furthermore, according to big bang theory, galaxies are randomly scattered throughout space by the billions, which also means that the distribution of redshifts

<sup>33</sup> Flamsteed, 1995, Discover, 68.

<sup>34</sup> Redshift refers to the displacement of spectral lines obtained from starlight. This displacement indicates that the original starlight has lengthened its wavelength and decreased in frequency. For a fuller treatment of redshift, see this study's Appendix.

values should be evenly distributed on average throughout all of space. But this is not the case.

The problem is somewhat analogous to police officers using radar guns to detect speeding vehicles but finding that all vehicles are traveling at exactly 50 or 60 or 70 miles per hour. This would mean that vehicles would have to change speeds instantaneously from 50 to 60 or 70 mph without passing through intermediate speeds, a feat that is impossible for current vehicles. Likewise, if the universe is expanding as big bang theory claims, and if the current expansion rate based on observational data is somewhere between 30 to 100 km per second megaparsec, then redshift values should also be amply found at values other than quantized ones. Thus, current big bang theory is inconsistent with observational redshift quantization.

Tifft has recently stated the serious implications of his findings:

The amount of...redshift increases with distance, [this is] the well-established Hubble's law. But to jump from this fact to the concept of the expanding universe, cosmologists have made a crucial assumption: that the redshift is a Doppler shift, representing motion away from us rather than some other physical effect. It seems like a straightforward assumption, but the picture it implies is not without problems, a major one being that galaxies move faster than the amount of visible mass would imply. To produce this extra motion, most astrophysicists believe that there must be some unseen mass, of unknown type. Yet searches for this "dark matter" have repeatedly failed. Slowly, researchers are realizing that even the most venerable of assumptions may have to be re-examined. The classical interpretation of redshift is the most venerable of them all.<sup>35</sup>

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<sup>35</sup> William G. Tifft, "A Brief History of Quantized Time," Mercury (September-October 1995): 13.

Tiff's above insight is quite perspicacious and trenchant. But a re-examination of such a fundamental assumption as the classical redshift interpretation-theory is likely to meet with resistance since this might not only undermine big bang cosmology but even expansion theory itself. Therefore, it is worthwhile to first examine the reasons for initially adopting the optical-Doppler and space-expansion redshift theories and, consequently, expansion theory.

## CHAPTER III

### THE SHIFT FROM STATIC TO RELATIVISTIC-EXPANSION COSMOLOGICAL THEORY

This chapter seeks to determine whether there were good and compelling reasons for the cosmological community to shift from a nonexpansion to an expansion view of the universe in the early 1930s. Fundamental to this shift was the discovery and interpretation of spectral redshifts as first optical Doppler effects and then space-expansion<sup>36</sup> results. In order to better understand the reasons and dynamics for choosing these redshift theories and an expanding universe theory, it is advantageous to examine the relevant historical cosmological developments and perspectives which led to the adoption of these theories.<sup>37</sup>

This chapter is organized into three main sections: (1) Spectral Redshifts And An Optical-Doppler Redshift Theory; (2) Relativity Theory, An Optical-Doppler Redshift Theory, A Redshift-Distance Relation, And Nonexpansion Cosmological

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<sup>36</sup> Technically, redshifting caused by space expansion is commonly referred to as either "cosmological redshift" or "cosmic redshift." But in order to avoid any potential confusion due to the various uses and applications of the term "cosmological" throughout this study, the terminology "space-expansion redshift" will be adopted instead.

<sup>37</sup> The historical scope roughly covers the nineteenth and the first three decades of the twentieth century. Since this historical period covers a vast expanse of time as well as scientific concepts and developments, whatever is chosen to recount is of necessity selective. Furthermore, the organization and presentation of any historical information entails selectivity. Therefore, this study provides at best a historical perspective of this period, not the definitive perspective. Nonetheless, it has been this study's concern to carefully and accurately approximate a fair portrayal of this time period.

Theory; and (3) Relativistic-Expansion Cosmological Theory, A Redshift-Distance Relation, And A Space-Expansion Redshift Theory. Each of these three sections is further subdivided into a concise overview, a historical part, and a corresponding evaluation part.

### Spectral Redshifts and an Optical-Doppler Redshift Theory

#### Overview

By the end of the nineteenth century, astronomers had discovered that some celestial phenomena were producing spectral redshifts, which they began interpreting as optical Doppler effects. This meant that these celestial phenomena were receding from earth at certain velocities. Although this redshift theory was questioned, eventually it was accepted largely due to the work of American astronomer V. M. Slipher during the first two decades of the twentieth century. The developments leading to the optical Doppler theory of spectral redshifts are quite informative and will now be described.

#### History

At the outset of the nineteenth century, astronomers believed the universe was static. This meant that, although the planets moved in their relatively fixed elliptical orbits (i.e., they possessed "peculiar motions"), the universe wasn't increasing or decreasing in its overall size, nor were planets or stars only receding from each other

or the earth. In other words, the universe was nonexpanding,<sup>38</sup> and everything was working like clockwork and according to Newtonian laws of physics.

By the close of the century, however, the foundations were being laid to change this view. This resulted primarily from developments in the areas of nebulae research, spectroscopy, optical Doppler theory, the speed of light, and spectral redshifts.

### Nebulae Debate

In the light of today's astronomical progress, it is not too difficult to agree on a definition of nebula. A nebula is "a cloud of interstellar gas and dust...."<sup>39</sup> But for at least over two centuries the term was very "nebulous," hence its nomenclature: "The term 'nebula' was originally applied to any object that appeared fuzzy and extended in a telescope."<sup>40</sup> Although the eighteenth-century Messier catalogue listed over one-hundred nebulae, it wasn't until much later that most of these objects were identified as galaxies and star clusters.

At the beginning of the nineteenth century, nebulae could mean any of several things: (a) bright patchy objects within or without our solar system, (b) gas rings around planets, (c) gaseous planetary atmospheres, (d) gas clouds, (e) star clusters, or (f) island universes - i.e., sun-star systems located far away from our own.

<sup>38</sup> Throughout this study, "expansion of the universe" will be defined as the increasing of the universe's overall size, not celestial bodies traveling through space in a recessional motion. This definition is in accordance with what appears to have historically been meant in the 1930s as well as today.

<sup>39</sup> Valerie Illingworth, The Facts on File Dictionary of Astronomy, 3d ed. (New York: Facts On File, 1994), 298.

<sup>40</sup> Ibid., 299.

Astronomers could only hope to solve the nebula-identity problem, known as the Great Debate, through the use of telescopes. However, they began to realize that developments in spectroscopy and the discovery of the optical Doppler effect could help them resolve the nebula-identity problem.

### Spectroscopy<sup>41</sup>

Although the application of spectroscopy to astronomy was first attempted by William Wollaston in 1802 England, more significant was the work of German optician Joseph Fraunhofer. In 1814, he observed and catalogued many absorption lines<sup>42</sup> in the spectrum of sunlight.<sup>43</sup> This led to a long-term interest in laboratory spectral analysis of the gaseous forms of the known earth elements to find their fingerprints; it was believed that each chemical element produced its own unique pattern of spectral lines. At times, laboratory experiments were also conducted to determine the composition of our sun. But this was accompanied with difficulty due to chemical impurities in the laboratory, which the Scottish optician David Brewster unfortunately learned from personal experience: after believing he had discovered the chemical composition of the sun, he then realized he had been merely analyzing the noxious vapors in his own lab!<sup>44</sup>

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<sup>41</sup> For a description and explanation of spectroscopy, see this study's Appendix.

<sup>42</sup> For a description and explanation of absorption and emission lines and spectra, see this study's Appendix.

<sup>43</sup> John B. Hearnshaw, "Spectroscopy," in Cosmology: Historical, Literary, Philosophical, Religious and Scientific Perspectives, ed. Norriss S. Hetherington (New York: Garland Publishing, Inc., 1993), 308.

<sup>44</sup> John B. Hearnshaw, "Spectroscopy and Cosmology," in Encyclopedia of Cosmology, Historical, Philosophical and Scientific Foundations of Modern

Nonetheless, notwithstanding such temporary setbacks, spectroscopy was used to determine earth-element fingerprints, which eventually were compared with spectra from celestial phenomena to ascertain their compositions. But it would be the celestial phenomena's shifted spectral lines that would lead cosmologists to conclude the universe is expanding. Yet such an inference needed an acceptable explanation for the cause of these shifts. Such an explanation was initially provided by the optical-Doppler theory.

### Optical Doppler Theory<sup>45</sup>

In the early 1840s, the Doppler theory was formally presented to the scientific community. This concept would eventually nudge the fields of astronomy, spectroscopy, and cosmological theory into an enduring unity.

In 1842, a professor of mathematics in Prague named Christian Doppler delivered a lecture to the Royal Bohemian Scientific Society. Part of his lecture posited both the sound and optical Doppler effects. Concerning the latter, Doppler hypothesized that the frequency and wavelengths of visible light should be altered due to any change in the motion of either the light source (such as the sun or a star) or the light receiver (such as the Earth) when moving toward or away from each other.

Although the Dutch physicist C.H.D. Buys-Ballot soon confirmed the Doppler theory for sound waves in 1845 from experiments on moving trains, both he and other

Cosmology, ed. Norriss S. Hetherington (New York: Garland Publishing Inc., 1993), 618.

<sup>45</sup> For a fuller treatment of the Doppler theory, see this study's Appendix.

scientists were sceptical as to the validity of the optical Doppler theory.<sup>46</sup> It would take a few more decades before empirical confirmation for the optical Doppler theory would be acquired.

### The Speed of Light

Meanwhile, scientists had begun to advance in an understanding of the speed of light. The first terrestrial measurement of light speed was made by the French scientist A.H. Fizeau in 1849.<sup>47</sup> In 1862, Leon Foucault made a more successful measurement,<sup>48</sup> and James C. Maxwell's 1873 theory of electromagnetic radiation led to other methods of light-speed measurements.<sup>49</sup> By the late 1880s, scientists became more confident about using the speed of light in mathematical calculations when the 1887 Michelson-Morley experiments showed that light was not bound to ether, if there was an ether, which was believed to permeate space.<sup>50</sup> This increasing understanding of light speed would assist astronomers in determining celestial phenomena velocities.<sup>51</sup>

<sup>46</sup> Ernst W. Otten, "Doppler Effect," in McGraw Hill Encyclopedia of Science and Technology, Vol. 5, 6th ed., (New York: McGraw Hill Inc., 1987), 389.

<sup>47</sup> George W. Stroke, "Light," in McGraw Hill Encyclopedia of Science and Technology, Vol. 10, 7th ed., (New York: McGraw Hill Inc., 1992), 50.

<sup>48</sup> Bernard Grun, The Timetables of History, 3d ed., based on Werner Stein's Kulturfahrplan (New York: Simon & Schuster, 1963), 425.

<sup>49</sup> Stroke, 50.

<sup>50</sup> Otten, 389.

<sup>51</sup> Light travels at approximately 300,000 kilometers per second.

### Spectral Redshifts, Optical Doppler Confirmation, and Velocities

By the early 1860s, the stage had been set for astronomers to use spectroscopy not only to ascertain the chemical compositions of celestial phenomena, but also to try to determine their velocities from a Doppler effect that would show up in the shifting of spectral lines. If an object was moving away from earth, it should show a spectral redshift; if it was approaching earth, then it should manifest a spectral blueshift.

Confirmational evidence for the optical Doppler theory was finally obtained in the 1870s. In 1860 the German physicist Ernst Mach and in the 1870s Fizeau independently predicted that if the sun was moving, its spectral lines would shift.<sup>52</sup> Their prediction was verified in the early 1870s when German astrophysicist H.C. Vogel observed a spectral-line shift in the spectrum from the sun's equatorial region. This shift due to solar rotation confirmed the optical Doppler theory. The velocity difference deduced was approximately two kilometers per second, which corresponded with the then-known solar rotation rate estimated from sunspots.<sup>53</sup> Others repeated and confirmed Vogel's observations in both the United States and Europe.<sup>54</sup>

Although empirical confirmation of the optical Doppler theory was not acquired until the 1870s, Englishman William Huggins had begun using spectroscopy and determining radial velocities already in the 1860s. In 1864, he found the emission spectral lines of eight nebulae. Over the next few years he extended his work to about

<sup>52</sup> Alan H. Guth, "Inflationary Universe," in Encyclopedia of Cosmology, Historical, Philosophical and Scientific Foundations of Modern Cosmology, ed. Norriss S. Hetherington, 1993, 303. Actually, Fizeau made this prediction in an 1848 lecture, but it wasn't published until 1870. See John B. Hearnshaw, "Doppler, Christian (1803-1853)" in Encyclopedia of Cosmology, ed. Hetherington, 179-80.

<sup>53</sup> Hearnshaw, "Spectroscopy and Cosmology," 615.

<sup>54</sup> Hearnshaw, "Spectroscopy," 304.

seventy more nebulous objects. A third of these revealed emission lines, which he concluded were masses of gas. The remaining objects showed either continuous or stellar absorption spectra, and he assumed that whatever they were, they were not gas. One of the continuous spectrum objects happened to be Andromeda (M31).<sup>55</sup>

In 1868, Huggins made the first spectroscopic measurement of the radial velocity of a star, as interpreted from its redshift, when he discovered that the nearby star Sirius was receding from the earth at about 30 miles per second. This finding was considered debatable, and it was later found to be incorrect.<sup>56</sup> Still, a velocity calculation had been made based on the optical Doppler theory of redshifts.

Scientists became much more certain it was feasible to measure stellar Doppler shifts when Potsdam Observatory astronomers Vogel and Julius Scheimer began recording stellar spectra via photography in 1888. Four years later, they had determined radial velocities for 52 stars based on their spectral shifts. Doppler spectral shifts in nearby binary stars were also being measured by Edward Pickering, director of the Harvard College Observatory.<sup>57</sup>

### Nebulae Debates Revisited

By the 1890s, a 36-inch telescope was considered a "giant," and California's Lick Observatory had one. Lick astrophysicist James E. Keeler was able to use this telescope to settle an old dispute: can "gaseous nebulae" move as fast as stars. He

<sup>55</sup> Ibid., 309-10.

<sup>56</sup> Robert W. Smith, The Expanding Universe: Astronomy's 'Great Debate' 1900-1931 (Cambridge, Mass.: Cambridge University Press, 1982), 17; see section referring to W. Huggins, 1968. Also John B. Hearnshaw, "Spectroscopy," 304-5.

<sup>57</sup> Hearnshaw, "Spectroscopy," 304-5.

concluded they can. Keeler also reported that most nebulae were spiral in shape, which also either started or exacerbated a new form of the nebulae debate that they were either purely gaseous and thus the birthplace of baby stars or they were island universes, which were thought to be a mixture of gases and material objects.<sup>58</sup> This latter debate would lead American astronomer Edwin P. Hubble to investigate spiral nebulae and eventually conclude that there existed a velocity-distance relation in the universe, which would be interpreted to mean the universe was expanding.

### A Caveat

At the turn of the century, examining celestial-phenomena spectra for Doppler redshifts had become somewhat established. Yet not everyone was comfortable with this theory of spectral redshifts. In 1901, W. Michelson wrote an article entitled "On Doppler's Principle."<sup>59</sup> In the article he claimed that a change in the thickness, density, index of refraction, as well as any movement of an intervening interstellar medium could impart a redshift in the wavelength of a light ray passing through the medium.

Michelson also pointed out some possibly questionable assumptions made when applying the Doppler theory to spectral redshifts:

But some of the assumptions on which its [the Doppler theory's] application is based are in great measure arbitrary, and can hardly be proved except *a posteriori*, by experimental verification. I shall mention but two of these assumptions: (1) that the period of vibration of the source is not influenced by its motion along the line of sight; (2) that the medium carrying on the waves is at rest as a whole, and that its properties are not changing.<sup>60</sup>

<sup>58</sup> Smith, Expanding Universe, 7-8.

<sup>59</sup> W. Michelson, "On Doppler's Principle," Astrophysical Journal 13, no. 4 (1901): 192-8.

<sup>60</sup> *Ibid.*, 192.

Michelson took pains to explain that he didn't want to overthrow Doppler's principle; he only wanted to suggest possible spectral displacements due to causes other than the motion of the light source or the observer. He explained that such considerations seemed reasonable, especially since there were many unknowns concerning the millions or billions of miles of interstellar space over which light travelled:

It is quite different when we are observing the displacement of lines in the spectra of celestial bodies. In this case we can neither verify immediately nor prove indirectly either of the assumptions referred to. It is very likely that these displacements are actually due to those motions by which they are usually explained in astrophysics, but, from a strictly logical point of view, it cannot be asserted as yet that no other explanation is possible....All I want is to give it [Doppler's principle] a somewhat different expression in order to comprise under one law also those cases where a change of the frequency is caused not only by the motion of the source or that of the observer, but also by a rapid alteration in the density of the medium crossed by the ray.<sup>61</sup>

Michelson also detailed the many unknowns in the case of emitted photons originating from the sun, passing through its different layers, meeting various types of laterally-moving densities, and thus having their optical paths between origin and observer lengthened, resulting also in the wavelength being elongated by the time it reached a terrestrial prism or spectroscope.

Yet in spite of Michelson's caveat, the Doppler theory gained greater confidence largely due to the work of American astronomer V.M. Slipher.

#### V. M. Slipher

Also in 1901 young astronomer Vesto Melvin Slipher joined the staff of the Lowell Observatory in Flagstaff, Arizona. His first assignment was to calculate the rotation of the Andromeda nebula, which at that time was regarded as a planetary

<sup>61</sup> Ibid., 192-93.

system beginning to form. Slipher did measure Andromeda's rotation, but of more lasting import was his seven-hour-exposure photographing of the Andromeda nebula's spectrum on October 17, 1912. Via spectroscopy, he provided the first measurement of Andromeda's radial velocity. This was also the first measurement of any spiral nebula's radial velocity.<sup>62</sup>

Andromeda's velocity was calculated as -300,000 km/s, which indicated a blueshift; this meant that the Andromeda galaxy was approaching our solar system. Since he was a cautious astronomer, he further collected several additional long-exposure photographic plates of the shifts in Andromeda's spectral lines, applied the Doppler theory, and found a sufficient consistency in his results.<sup>63</sup>

Still hesitant to publish too fast, Slipher took very long exposures of other nebulae as well, some with exposures up to 40 hours each. Most of these spectra had absorption lines that showed large shifts toward the red, which were perplexing because previously astronomers had only noted small redshifts.<sup>64</sup>

After some time, Slipher developed an explanation for his anomalous large redshifts. He stated that nebulae which cover vast areas possessed low surface brightness, which had previously resulted in inaccurate small redshift observations.

<sup>62</sup> Slipher seems to have always used spectral line shifts to determine velocities. Therefore, whenever he reports velocities, the reader may understand he is reporting a Doppler-velocity interpretation of spectral shifts. See Robert W. Smith, "Edwin P. Hubble and the Transformation of Cosmology," Physics Today (April 1990): 52-58.

<sup>63</sup> Robert W. Smith, "Cosmology 1900-1931," in Cosmology: Historical, Literary, Philosophical, Religious and Scientific Perspectives, ed. Norriss S. Hetherington (New York: Garland Publishing, Inc., 1993), 333.

<sup>64</sup> David H. Levy, "A Grand Gathering of the Galaxies," Astronomy 19, no. 3 (March 1991): 46; Hubble, Edwin, Realm of the Nebulae (New York: Dover Publications, 1936 and 1958): 69.

But in September of 1912, his spectrograph had been fitted with a very fast lens, which he claimed was about 200 times faster than the usual spectrograph. Consequently, due to his modified spectrograph coupled with long time exposures, he was able to obtain more accurate redshift measurements.<sup>65</sup>

Slipher finally published his results in the 1913 Lowell Observatory Bulletin.<sup>66</sup>

Other astronomers quickly confirmed his results while he continued obtaining "comparable values" for other spirals.<sup>67</sup>

In August of 1914, Slipher delivered a paper on spectrographic observations of nearly 40 spiral nebulae at an American Astronomical Society meeting. He had now determined the radial velocities of 15 spiral nebulae, including two spirals that were receding at 1,100 km per second. Slipher presented quality photographs showing how the absorption lines were characteristic of collections of stars. He also pointed out how the wavelengths of the nebular absorption lines were offset from where they should appear. Slipher's findings were significant. The Doppler-velocity shifts indicated that the spiral nebulae were moving far faster than is typical for stars within the Milky Way, which strengthened the argument that they were not part of our galaxy.<sup>68</sup>

Slipher's colleagues demonstrated their acceptance of his results with a standing ovation. Young Edwin Hubble, who was present at this meeting, may have been impressed along with others with the intriguing fact that almost all the spiral

<sup>65</sup> Smith, Expanding Universe, 38.

<sup>66</sup> Vesto M. Slipher, Lowell Observatory Bulletin, no. 58, 1913.

<sup>67</sup> Smith, Expanding Universe, 39.

<sup>68</sup> Donald E. Osterbrock, Joel A. Gwinn and Ronald S. Brashear, "Edwin Hubble and the Expanding Universe," Scientific American 269, no. 1 (July 1993): 86.

nebulae velocities were positive, which indicated they were receding: "...only the Andromeda nebula and its nearest neighbors in the sky had negative velocities. The average velocity of nebulae was 400 km/s, exceeding the stellar velocities by a factor of 25."<sup>69</sup>

A short article based on Slipher's August 1914 lecture was published the next year. In this article, Slipher comments on his increased interest in determining velocities:

When entering upon this work it seemed that the chief concern would be with the nebular spectra themselves, but the early discovery that the great Andromeda spiral had the quite exceptional velocity of -300,000 km showed the means then available, capable of investigating not only the spectra of the spirals, but their velocities as well. I have given more attention to velocity since the study of the spectra had been undertaken with marked success by Fath at Lick and Mount Wilson, and by Wolf at Heidelberg.<sup>70</sup>

On April 13, 1917, Slipher presented a report entitled "Nebulae" at an American Philosophical Society meeting.<sup>71</sup> He summarized some of the Mount Wilson and Lick work on spiral nebulae, and he explained some of the problems in getting spectral data from faint nebulae. But of more interest relevant to this study is Slipher's comments on the receding spirals and their identities:

Referring to the table of velocities again: the average velocity 570 km. is about thirty times the average velocity of the stars. And it is so much greater than that known of any other class of celestial bodies as to set the spiral nebulae aside in a class to themselves. Their distribution over the sky likewise shows them to be unique - they shun the Milky Way and cluster about its poles....It has for a long time been suggested that

<sup>69</sup> Alexander S. Sharov and Igor D. Novikov. Edwin Hubble, the Discoverer of the Big Bang Universe (Cambridge University Press, 1989), 49.

<sup>70</sup> Vesto M. Slipher, "Spectrographic Observations of Nebulae," Popular Astronomy 23 (1915): 22-23.

<sup>71</sup> It was printed in Proceedings of the American Philosophical Society 56 (1917): 403-409, under the title "A Spectrographic Investigation of Spiral Nebulae."

the spiral nebulae are stellar systems seen at great distances. This is the so-called "island universe" theory, which regards our stellar system and the Milky Way as a great spiral nebula which we see from within. This theory, it seems to me, gains favor in the present observations.<sup>72</sup>

Thus Slipher had taken a position concerning the nebulae debate: spiral nebulae were very distant stellar systems (i.e., galaxies), which were receding from earth. And this position was based on a Doppler theory of spectral redshifts.

The upshot of Slipher's research on spiral nebulae finally was presented to the general public in a 1921 New York Times article on his recent observations of Nebula No. 584 in the constellation Cetus. In this article, Slipher explained how he determined velocity from redshift data:

It is necessary to disperse the nebular light into a spectrum in order to observe the spectral lines, and to measure the amount they are shifted out of their normal positions, for it is this displacement of the nebula's lines that discloses and determines the velocity with which the nebula is itself moving. The lines in its spectrum are greatly shifted, showing that the nebula is flying away from our region of space with a marvelous velocity of 1,100 miles per second.<sup>73</sup>

In the same article, Slipher surprisingly also posited the nebula's distance from earth, based on the then-known (but incorrect) age of the earth:

If the above swiftly moving nebula be assumed to have left the region of the sun at the beginning of the earth, it is easily computed, assuming the geologists' recent estimate of the earth's age, that the nebula now must be many millions of light years distant.<sup>74</sup>

Although Slipher's attempt at distance calculation was later shown incorrect, it still was significant: if corresponding distances could be determined for the spiral

<sup>72</sup> Vesto M. Slipher, "A Spectrographic Investigation of Spiral Nebulae," Proceedings of the American Philosophical Society 56 (1917): 407, 409.

<sup>73</sup> Vesto M. Slipher, "Dreyer Nebula No. 584 Inconceivably Distant," New York Times (19 January 1921): 6.

<sup>74</sup> Ibid.

nebulae whose velocities had been calculated via the Doppler redshift theory, then a comparison could be made to see if there existed in the universe a velocity-distance relation. If there existed such a relation, this could be seen as evidence for the expansion of the universe. But the determination of this relation involves the work of Hubble, which will be covered in the next historical section of this chapter.

### Evaluation

Given the above historical account, there were good and compelling reasons for astronomers - Slipher in particular - to adopt the optical-Doppler redshift theory. One reason was that the optical-Doppler redshift theory could explain the redshift data, was more or less confirmed, and didn't have to contend with any disconfirmational evidence.. For instance, in 1842 Christian Doppler proposed the optical-Doppler redshift theory, and by the 1870s German physicist Ernst Mach and French scientist A.H. Fizeau had independently predicted spectral-line shifts from the moving sun, which was tested and verified by the German astrophysicist H.C. Vogel in the 1870s as well as others in both the United States and Europe.

A second reason was that the optical-Doppler redshift theory was the only viable redshift theory available at the time. Although in 1901 W. Michelson issued a caveat against accepting the optical-Doppler redshift theory too quickly since it was possible that spectral displacements could be due to an interstellar medium, this alternative redshift theory did not possess as good and compelling reasons for adoption as did the optical-Doppler redshift theory in at least three ways. First, although Michelson's redshift theory could account for the redshift data, there was no confirmational evidence at the time that light would be reddened due to an interstellar medium. Second, the 1887 Michelson-Morley experiment seemed to indicate that

light was not affected by an interstellar medium, especially the then-believed ether medium which was supposed to permeate space. Third, there was no blurring of spectral lines, which was expected to occur if light had been affected by some interstellar medium. Therefore, the cosmological community had good and compelling reasons to adopt the optical-Doppler redshift theory at this time in history.

### Relativity Theory, an Optical-Doppler Redshift Theory, a Redshift-Distance Relation, and Nonexpansion Cosmological Theory

#### Overview

During the nineteenth century, Europeans had forged the way in both theoretical and observational astronomy. This would change in the first half of the twentieth century. Although Europeans would continue to excel in the theoretical arena, by the end of World War I Americans would emerge as the authority in observational astronomy because they possessed the best astronomical technology.

Yet European and American astronomy were not totally isolated from one another. While European focus was on relativity theory and the possible static and expansion theoretical universes it could produce, American astronomer Edwin Hubble decided to see if there existed any observational basis for such theoretical universes. In 1929, he would offer evidence that there existed a velocity-distance relation, which would significantly influence the adoption of expansion theory in the early 1930s.

## History

### Relativity Theory

In the early twentieth century, Albert Einstein announced his two theories of relativity, which changed the way cosmologists looked at the universe. In 1905, Einstein published his special theory of relativity. In 1915, he finished formulating his general theory of relativity and published it in its final form the following year.

Although there is no quick and simple way to summarize and explain Einstein's theories, an abbreviated list of relativity concepts germane to this study are offered below:

1. All laws of nature are the same in all uniformly moving frames of reference.

2. Space and time are united as space-time, which is a curved continuum. In addition: (a) curved surfaces have properties analogous to gravity; (b) gravity and inertia have indistinguishable effects; (c) the curvature of space-time is influenced by matter; and (d) the ripples traveling outward from gravitational sources are called gravitational waves, and any moving object produces a gravitational wave proportional to its mass and motion.

3. Mass and energy are equivalent and interconvertible.

4. Mass cannot attain the speed of light since it would then become infinite.

This would mean that an infinite force would be needed to accelerate the mass to the speed of light, which is impossible. (This point becomes important later on when spectral redshifts threaten to indicate superluminal speeds).

With the theory of relativity relatively articulated, the next logical step was to apply it and determine what kind of universe does or could exist. Albert Einstein and Willem de Sitter became pioneers in this endeavor.

### The 1917 Einstein Universe

In Berlin, Einstein formulated his mathematically-based relativistic universe, which he presented in a 1917 paper.<sup>75</sup> He had already argued in his general theory of relativity that the space-time continuum was curved, so he decided to regard the universe as a spatially-curved continuum. In addition, he assumed the prevailing view of a static universe with infinite space, and he also decided to accommodate the available observational data concerning star distribution.

Since Einstein believed that space-time didn't exist without gravity, he concluded it would disappear at infinity. Therefore, he set out to describe the boundary conditions for his universe. But due to logical and equation conflicts, he finally gave up on an infinite spatial universe.

Einstein then turned his attention to describing a finite universe filled with a static distribution of matter (i.e., no large-scale motions of stars or nebulae). Since this universe was finite or closed, there was no need for any boundary conditions, which solved his previous boundary problems. Furthermore, he assumed that matter was uniformly distributed over large sections of space-time; this was a bold assumption since astronomical knowledge at the time was basically limited to the Milky Way Galaxy, which appeared to be inhomogeneous. In addition, Einstein assumed isotropy for the large-scale distribution of matter. These two assumptions for

<sup>75</sup> Albert Einstein, "Cosmological Considerations on the General Theory of Relativity," Sitzungsberichte der Preussischen Akad. d. Wiss (1917): 142-52, translated by editors, in Cosmological Constants: Papers in Modern Cosmology, eds. Jeremy Bernstein and Gerald Feinberg (New York: Columbia University Press, 1986), 16-26.

the large-scale distribution of matter have come to be known as the "cosmological principle."<sup>76</sup>

Perhaps of most interest to this study is Einstein's solution to preserve a static universe. Based on his calculations, Einstein realized that his universe would either collapse or expand. He was more concerned about the former because it seemed most likely to occur as the result of gravity acting on the universe's matter. In order to maintain a static universe, Einstein arbitrarily incorporated an antigravitational repulsive force, called the cosmological constant, in order to balance the universe's matter. The result was a finite, static universe.

### The 1917 De Sitter Universe

Willem de Sitter, a professor of astronomy at Leiden University in the Netherlands, quickly objected to Einstein's model of the universe on the grounds that it didn't completely satisfy observational data. Although Einstein had calculated the mass of his universe to be finite, de Sitter quickly pointed out that the amount of mass needed to close space-time in Einstein's model clearly surpassed that of the observed planets, stars, and nebulae.<sup>77</sup> Consequently, de Sitter provided his own cosmological model, which came to be known as "the de Sitter universe" or "de Sitter space."

Like Einstein, de Sitter assumed a static universe and the cosmological constant. But unlike Einstein, de Sitter concluded that the radius of the universe must be greater than that of Einstein's universe, given the calculated mass of the universe.

<sup>76</sup> Pierre Kerszberg, "Relativistic Cosmology," in Encyclopedia of Cosmology: Historical, Philosophical and Scientific Foundations of Modern Cosmology, ed. Norriss S. Hetherington (New York: Garland Publishing, Inc., 1993), 569-70.

<sup>77</sup> Ibid., 570.

The result was a static universe in which the observed mass turned out to be negligible or practically nonexistent.<sup>78</sup>

Almost everyone thought his no-mass universe was absurd. In fact, the de Sitter universe would probably have been ignored, except for its repulsion attribute. De Sitter had noted that if any matter was "sprinkled" into his universe, it would be repelled due to the antigravitational repulsion forces. This repulsion, which would later be called the "de Sitter effect," seemed able to account for observed recessional velocities. De Sitter reflectively noted this possibility in his famous Postscriptum to his 1917 article, which presented his relativistic universe.

The events surrounding the writing of the Postscriptum are noteworthy. During World War I, it was difficult to disseminate astronomical data throughout Europe. British astronomer Sir Arthur Eddington had attempted to spread new cosmological knowledge throughout Europe, especially the data being acquired by American astronomers. Shortly after de Sitter finished writing his 1917 article but before sending it for publication, he received news from Eddington concerning four of Slipher's redshift observations. This inspired de Sitter to write a postscriptum, which was longer than the original article!

In the Postscriptum, de Sitter predicted a redshift-velocity-distance relation. If his cosmological theory represented a good approximation of the actual properties of the universe, then a relation between redshift-velocity and distance would be expected, if matter were "sprinkled" into the de Sitter universe. He suggested that the greater the distance, the greater would be the redshift-velocity of celestial phenomena, since

<sup>78</sup> Willem de Sitter, "On Einstein's Theory of Gravitation, and Its Astronomical Consequences," Monthly Notices of the Royal Astronomical Society, 78 (1917): 3-28.

the repulsion forces would overcome gravitational forces and accelerate the matter in opposite directions. But this prediction, he noted, would not be verified without accurate distances to faint nebulae, which were believed to be very distant. Although he was cautious not to jump to any conclusions, de Sitter seemed to hold out some hope based on the acquired data:

Spiral nebulae most probably are amongst the most distant objects we know. Recently a number of radial velocities of these nebulae have been determined [by Slipher]. The observations are still very uncertain, and conclusions drawn from them are liable to be premature. Of the following three nebulae, the velocities have been determined by more than one observer....These velocities are very large indeed, compared with the usual velocities of stars in our neighborhood.<sup>79</sup>

### Distance Measurements

While the above theoretical developments were taking place, observational astronomers were attempting to calculate accurate distance measurements in addition to collecting spectral-redshift data of celestial phenomena. The distances of these celestial phenomena were very difficult to measure, especially in the case of spiral nebulae which were believed to be very far away. But by about 1909, assistant astronomer Henrietta Leavitt of the Harvard Observatory offered a solution.

Through persistent careful observations and analysis, Leavitt established an apparent way to determine distances by using stars called Cepheid variables, which periodically and predictably pulsate in brighter-dimmer cycles. She recognized a relation whereby a Cepheid variable's period of pulsation and average apparent magnitude (i.e., how faint or bright it appears through a telescope) can lead to determining its absolute magnitude (i.e., its true or actual brightness). By further independently establishing distances for relatively nearby Cepheids and relating their

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<sup>79</sup> Ibid., 27.

distances to their respective period-luminosity relation, probable distances for Cepheids very far away could be established. In other words, nearby Cepheids could be used as normative extrapolation bases for determining far away distances.<sup>80</sup>

As a result of Leavitt's work, astronomers became confident that they had a key to determining distances. And where there seemed to be a rough correlation between Cepheid distances and redshifts, they became more convinced of a Doppler-redshift effect. In fact, by 1920 all three leading American Observatories were using some type of a velocity-distance relation, although none were uniformly convincing. It would take the work of Hubble to finally provide an acceptable relation. But first, he would focus on distance measurements.

In 1917, Hubble completed a doctorate at the Yerkes Observatory. His dissertation was based on photographs of seven clusters of nebulae taken between 1914 and 1916. At this time, only 76 nebulae in clusters were known. By the end of his career, however, Hubble would add another 512.

Hubble joined the Mount Wilson Observatory in 1919. He was a man of thoroughness, energy, confidence, and purpose, and his high productivity began right away. By 1920, he was already publishing regularly for Astrophysical Journal and for Publications of the Astronomical Society of the Pacific. He particularly focused on faint nebulae, always trying to determine which images were stars and which were gas clouds or "condensations" as well as estimating diameters and distances.

<sup>80</sup> Sharov, Edwin Hubble, 29; Henrietta S. Leavitt, "Periods of Twenty-five Variable Stars in the Small Magellanic Cloud," (1912), Harvard College Observatory Circular No. 173, reprinted in A Source Book in Astronomy and Astrophysics, 1900-1975, eds. Kenneth R. Land and Owen Gingerich (Cambridge: Harvard University Press, 1979), 399-400.

In 1920, Hubble published the spectrum of a group of faint nebulae collectively called NGC1499 and showed that their emission lines revealed hydrogen, helium, and oxygen.<sup>81</sup> Next he wanted to test his hypothesis that stars were the source of light from nebulae with continuous spectra. From his photographs, Hubble showed in 1922 that the size of a nebula was related to the apparent magnitude of a star seen either in or next to that nebula.<sup>82</sup> In 1923, he began to study novae (stars in a state of partial explosion) in the spiral nebulae. Counting on the "principle of the uniformity of nature," he hoped that novae in the Andromeda Nebula would average out to the same brightness as novae in the Milky Way, and he further hoped to use comparisons of apparent brightnesses to estimate the distance to the Andromeda Nebula with more certainty. He was thrilled to find in Andromeda not only novae, but at least one Cepheid variable. Hubble quickly estimated Andromeda's distance to be about one million light-years away.<sup>83</sup>

By the end of 1924, Hubble had identified several more Cepheid variables in M31 and in M33, which he deduced were approximately 930,000 light-years away, far beyond the Milky Way itself. The American Astronomical Society's secretary Joel Stebbins declared that this was confirmation of the so-called island universe theory.<sup>84</sup>

Hubble's results were reported in Publications of the American Astronomical Society the following year. This article was unusually important for two reasons.

<sup>81</sup> Edwin P. Hubble, "The Spectrum of NGC1499," Publications of the Astronomical Society of the Pacific 32 (1920): 155.

<sup>82</sup> Idem, "The Source of Luminosity in Galactic Nebulae," Astrophysical Journal 56 (1922):400.

<sup>83</sup> Smith, 1990, Physics Today, 56.

<sup>84</sup> Osterbrock, 1993, Scientific American, 88.

First, Hubble had stated three assumptions: (1) Cepheid variables are actually connected with spiral nebulae, (2) there is no serious amount of absorption due to amorphous nebulosity in the spirals, and (3) the nature of Cepheid variation is uniform throughout the observable portion of the universe. In other words, Cepheid variables could be trustingly used, based on the "uniformity of nature" principle, to determine spiral nebulae distances. Second, this article was important because Hubble was believed to have confirmed that the "apparent magnitude vs. log of period" relation could be used with the "absolute magnitude vs. log of period" relation to establish astronomical distances to galaxies.

At this time, Hubble appears to have been becoming more definite about principles and methods by which distances from earth to nebulae and stars could be determined. For instance, he made the fundamental assumption that throughout the universe the Cepheids with the same periods have the same absolute magnitudes, which could be somewhat confidently used to calculate distances. Furthermore, he decided not to be too concerned that starlight shining through "nebulosity" (i.e., an interstellar medium or gas clouds surrounding a star) would significantly alter spectral readings and thus give an inaccurate distance or velocity. In 1926, Hubble clearly stated his uniformity assumption: "once the assumption of a uniform order of luminosity is accepted as a working hypothesis, the apparent magnitudes become, for statistical purposes, a measure of the distances."<sup>85</sup>

### Velocity-Distance Relation

With spectral redshift-velocity and distance measurements of celestial phenomena being collected, the way was prepared for Hubble to ascertain if there

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<sup>85</sup> Edwin P. Hubble, "Extra-Galactic Nebulae," Astrophysical Journal 64 (1926): 361.

existed a velocity-distance relation in the universe. Hubble's impetus for searching for such a velocity-distance relation came from European theoretical developments.

In 1926, Hubble began mentioning relativity theory in private notes and articles, sometimes attempting a minor comparison of results with relativity theory.<sup>86</sup> Two years later Hubble, aware of de Sitter's relativistic cosmological theory and its predicted velocity-distance relation, discussed theoretical and observational problems with colleagues at the 1928 International Astronomical Union meeting in Holland. He returned to Mount Wilson Observatory determined to test de Sitter's prediction.<sup>87</sup>

Hubble immediately put his hard-working assistant Milton Humason to work. Humason spent many long hours throughout the night taking long exposures of faint nebulae in a data-gathering endeavor. By the following year, Hubble was ready to publish the results in his landmark 1929 article.

Directly preceding Hubble's 1929 article in the same journal was one by Humason. Humason discussed the radial methodologies used, reported the data collected over the past year, and stated the purpose for undertaking these observations:

About a year ago Mr. Hubble suggested that a selected list of fainter and more distant extra-galactic nebulae, especially those occurring in groups, be observed to determine, if possible, whether the absorption lines in these objects show large displacements toward longer wavelengths, as might be expected on de Sitter's theory of curved space-time....Hubble, in a paper in these PROCEEDINGS, gives approximate distances for 24 extra-galactic nebulae, and finds a marked increase in radial velocity with distance. The high velocity for N.G.C.7619 derived

<sup>86</sup> Norriss S. Hetherington, ed., The Edwin Hubble Papers: Previously Unpublished Manuscripts on the Extragalactic Nature of Spiral Nebulae (Tucson: Pachart Publishing House, 1990), 115.

<sup>87</sup> Norriss S. Hetherington, ed., Cosmology: Historical, Literary, Philosophical, Religious and Scientific Perspectives (New York: Garland Publishing, Inc., 1993), 360.

from these plates falls on the extrapolated line which expresses the relationship between line displacement and distance [i.e., a redshift-distance graph]. These results suggest an influence of distance upon the observed line shift - such as would be produced, for example, on de Sitter's theory, both by the apparent slowing-down of light vibrations with distance and by a real tendency of material bodies to scatter in space.<sup>88</sup>

Humason explicitly stated that their findings revealed a redshift-distance relation, which was consistent with the de-Sitter-effect prediction.

In the next article, Hubble reported his findings and conclusions based on 46 extra-galactic nebulae. Hubble stated he had utilized apparent luminosities to estimate distances to galaxies. He then carefully discussed the relative certainty of the nebulae distances he selected to test for a linear direct relationship between their distances and velocities. After deciding, based on an assumed homogenous universe, that the luminosities of the brightest stars in nebulae were approximately equal, he compared the selected nebulae's calculated velocities and distances and concluded that a linear velocity-distance relation existed. Because new data was expected soon, Hubble thought it was "premature to discuss in detail the obvious consequences of the present results," but he couldn't refrain from stating that "the outstanding feature, however, is the possibility that the velocity-distance relation may represent the de Sitter effect, and hence that numerical data may be introduced into discussions of the general curvature of space."<sup>89</sup>

Historian Robert Smith comments on the significance of Hubble's 1929 article:

<sup>88</sup> Milton L. Humason, "The Large Radial Velocity of N.G.C. 7619," Proceedings of the National Academy of Science, 15, (March 1929): 167-8.

<sup>89</sup> Edwin P. Hubble, "A Relation Between Distance and Radial Velocity Among Extra-Galactic Nebulae," Proceedings of the National Academy of Sciences 15 (March 1929): 173.

"At first, using a few radial velocities secured at Mount Wilson by Milton Humason and many other velocities obtained earlier by Slipher, together with his own estimates of distances to the galaxies, Hubble persuaded his colleagues that, at least in the first approximation, there was a linear relationship between spectral shift and distance....Hubble's claims about a redshift-distance relation were generally regarded as much superior to those of earlier investigators. Not only did Hubble have estimates of distances to the galaxies regarded as more accurate than those used by others who had earlier sought to plot redshift against distance, but also Hubble's standing as a leading - if not the leading - student of galaxies (extragalactic nebulae in Hubble's terminology) and his use of the most powerful telescope in the world...were guarantees in the eyes of his colleagues of the credibility of his claims."<sup>90</sup>

A positive response to Hubble's 1929 article soon appeared later that same year. Henry Norris Russell, Chairman of the Department of Astronomy and Director of the Observatory at Princeton University, wrote an article entitled "The Highest Known Velocity."<sup>91</sup> In this article, Russell enthusiastically exuded over the grandeur of the incredible distances and stunning recession rates of the nebulae. After giving due credit to those who had worked so hard to gain this data, he explained spectral redshifting and described both the velocity-redshift theory and the velocity-distance relation as conclusively proved. But of most interest, Russell raised the question as to the meaning of "nebulae really flying out in all directions - away from us and therefore from one another - so that the universe of nebulae is expanding without limits into the depths."<sup>92</sup> He responded by explaining how in de Sitter's world, objects at great distances repel each other with forces increasing with distance. "If originally...they were fairly close together, they will, after the lapse of ages, be receding from one

<sup>90</sup> Smith, "Cosmology 1900-1931," 341.

<sup>91</sup> Henry Norris Russell, "The Highest Known Velocity," Scientific American 140 (June 1929): 504-505.

<sup>92</sup> Ibid., 504.

another with speeds proportional to their distances, just as Hubble's investigations indicate.<sup>93</sup>

### Evaluation

Given the above historical account, cosmologists had good and compelling reasons to believe there existed a redshift-distance relation and to interpret this relation as a velocity-distance relation.

First, Hubble's reported redshift-distance relation appeared to possess solid-verificational evidence and justification, especially since Hubble had access to the most powerful telescope of the time and was perceived as the authority in both distance measurements and extra-galactic nebulae research. So, there existed no reason to doubt the credibility of this relation.

Second, there were no new developments that provided any confirmational evidence for an alternative redshift theory such as Michelson's 1901 theory. Thus, the optical-Doppler redshift theory still had no competing redshift theory with any confirmationally-based evidence.

Third, as was discussed in the previous "evalution" section of this chapter, cosmologists had good and compelling reasons for applying the optical Doppler theory to spectral redshifts. Therefore, since there were no comparable competing alternative redshift theories, it was logical to infer that the redshift-distance relation was a velocity-distance relation.

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<sup>93</sup> Ibid.

## Relativistic-Expansion Cosmological Theory, a Redshift-distance Relation, and a Space-Expansion Redshift Theory

### Overview

While in the United States Slipher, Hubble, and others had been making spectral-redshift and distance measurements as well as collecting data for the confirmation of a velocity-distance relation, European theorists were engaged in developing mathematically-based cosmological theories incorporating Einstein's relativity theory and some observational data. During the 1920s, a few theorists produced models of expanding universes and published their findings. Their cosmological theories were neglected for the most part by cosmologists, who still viewed the actual universe as static. But when a cosmological crisis had escalated by the early 1930s largely due to Hubble's redshift-distance relation, Georges Lemaitre's expansion theory was hailed by the leading cosmologists as a solution. Consequently, there occurred a shift from viewing the actual universe as static to seeing it as expanding. Ever since, almost all cosmologists have pursued describing the actual universe as expanding.

### History

#### Relativity Theory Confirmed

By the end of World War I, Slipher's redshift results circulated more freely to scientists throughout Europe. Although Einstein's 1905 Theory of Special Relativity was already quite well-known, only a number of European cosmologists were aware of his General Relativity Theory, which had been published during the War. This would soon change due once again to the British astronomer Sir Arthur Eddington.

Eddington decided to test Einstein's relativity theory by empirical means. Einstein had predicted that starlight would show a particular deflection during the next total eclipse of the sun. So Eddington prepared an expedition to observe the total solar eclipse of May 29, 1919. After selecting an astronomically advantageous geographical location, Einstein's theory was declared confirmed by photographic evidence that starlight passing the totally eclipsed sun had been deflected as predicted. The news quickly spread around the world that Einstein's theory had been verified.<sup>94</sup>

### Carl Wirtz and Alexander Friedmann

By 1922, two scientists were making progress in developing expansion theory based on relativity theory. The first was German astronomer Carl Wirtz. Wirtz had studied both Slipher's redshift measurements and de Sitter's paper. Assuming the optical-Doppler redshift theory, he then proposed a velocity-distance relation and claimed that the greater a galaxy's distance, the smaller its apparent diameter. But unlike Einstein's relativity theory, Wirtz's prediction did not attract much interest.<sup>95</sup>

The second scientist to develop an expansion theory was Russian Aleksandr A. Friedmann, a mathematician and physics professor in Leningrad. In 1922, he published a paper entitled "On the Curvature of Space."<sup>96</sup> In this paper, Friedmann

<sup>94</sup> Sharov, Edwin Hubble, 54.

<sup>95</sup> Edward R. Harrison, Cosmology: The Science of the Universe (Cambridge: Cambridge University Press, 1981), 209.

<sup>96</sup> Aleksandr A. Friedmann, "On the Curvature of Space," in Zeitschrift fur Physik, 10 (1922): 377-86, translated by editors, reprinted in Cosmological Constants: Papers in Modern Cosmology, eds. Jeremy Bernstein and Gerald Feinberg (New York: Columbia University Press, 1986), 49-58.

described a hypothetical universe based on a class of solutions to Einstein's field equations. Although he referred to his model as a "periodic world," it also became known as the Phoenix Universe or a closed oscillating universe, where the universe's radius infinitely oscillates between zero and some maximum value.<sup>97</sup>

In a 1924 paper, Friedmann stated that the universe must either expand or contract because gravity dominates all aspects of the universe. If objects have enough velocity to expand, gravity will slow the expansion since gravitational forces would substantially manifest themselves only at very large cosmological distances. Only very special initial conditions would exactly balance the forces for expansion or contraction so that a static universe would exist.<sup>98</sup>

Although Friedmann's model was understood by contemporary cosmologists to be merely a hypothetical non-realistic world model, it troubled Einstein. Einstein was so sure of a static universe that he sent a letter to Zeitschrift fur Physik called "Remark on the Work of A. Friedmann...On the Curvature of Space."<sup>99</sup> Einstein remarked "The work cited contains a result concerning a non-stationary world which seems suspect to me. Indeed, those solutions do not appear compatible with the field equations...."<sup>100</sup>

<sup>97</sup> Helge Kragh, "Big Bang Cosmology," in Encyclopedia of Cosmology, ed. Norriss S. Hetherington, 1993, 33.

<sup>98</sup> Roth, J. and J.R. Primack, 1996, Sky & Telescope, 23.

<sup>99</sup> Albert Einstein, "Remark on the Work of A. Friedmann, (Friedmann 1922) 'On the Curvature of Space'," Zeitschrift fur Physik 11 (1922): 326, translated by editors, reprinted in Cosmological Constants: Papers in Modern Cosmology, eds. Jeremy Bernstein and Gerald Feinberg (New York: Columbia University Press, 1986), 66.

<sup>100</sup> Ibid., 326.

In response, Friedmann wrote a long explanation to Einstein, but Einstein ignored it until another physicist acting as a middleman had a series of discussions with him explaining the basis for Friedmann's expanding universe. Although Einstein still believed the actual universe was static in 1923, he wrote a retraction of his previous criticism.<sup>101</sup>

In spite of Einstein's retraction, Friedmann's model remained an intellectual curiosity and soon was forgotten, which most likely resulted from Friedmann's death in 1924; there was no one to champion it. Still, a relativistic expansion theory had been proffered.

### Georges Lemaitre

The most influential expansion theorist of perhaps the entire twentieth century was Georges Lemaitre - a Belgian abbe, physicist, and mathematician. Lemaitre developed an expansion theory known as the "Primeval Atom Hypothesis," which became the prototype for big bang theory.

Lemaitre did his academic thesis on relativity and gravitation. In 1924-5, he visited the United States and attended a joint meeting of the American Astronomical Society and the American Association for the Advancement of Science. At this meeting, he heard Hubble's paper on Cepheids in Andromeda read. Lemaitre decided

<sup>101</sup> Albert Einstein, "A Note on the Work of A. Friedmann 'On the Curvature of Space,'" Zeitschrift fur Physik 16 (1923): 228, translated by editors, reprinted in Cosmological Constants: Papers in Modern Cosmology, eds. Jeremy Bernstein and Gerald Feinberg (New York: Columbia University Press, 1986), 67.

to associate Hubble's observational findings with the models of de Sitter and Einstein.<sup>102</sup>

In his 1927 seminal paper,<sup>103</sup> Lemaitre presented his conclusions and criticized both models. He was able to develop de Sitter's solution to the general relativity's field equations, which showed it was a solution for an expanding universe. Although he had done this two years earlier, he now concatenated it with astronomical data.

Historian Robert Smith comments on the significance of this association:

In so doing, Lemaitre distinguished himself from other researches [sic] (such as Alexander Friedmann) who had investigated nonstatic solutions to the field equations of general relativity but had done so largely as mathematical exercises.<sup>104</sup>

Thus, Lemaitre introduced a space-expansion redshift theory whereby celestial-phenomena light is lengthened and reddened due to expanding space. In addition, he proposed that the universe was expanding by increasing its overall radius. The means by which the universe was increasing its radius was itself a novel idea: space itself was expanding. This accounted for the universe expanding in a linear manner according to the observed redshift-distance relation. Lemaitre also stated that the universe began expanding from an Einstein Universe in a state of equilibrium and was asymptotically approximating a de Sitter Universe. Although Lemaitre's solution would provide the

<sup>102</sup> Robert W. Smith, "Lemaitre, Georges (1894-1966)," in Encyclopedia of Cosmology, ed. Norriss S. Hetherington, 1993, 365.

<sup>103</sup> Georges Lemaitre, "Un univers homogene de masse constante et de rayon croissant, rendant compte de la vitesse radiale des nébuleuses extragalactiques," Annales de la Societe scientifique de Bruxelles. Serie A. Sciences mathematoques 47 (1927): 49-59. Reprinted in 1931, "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 (1931): 483-490.

<sup>104</sup> Smith, "Lemaitre, Georges," 366.

basis for big bang theory, it received little attention at the time, probably since it was published in an obscure journal.

### Cosmological Crisis

By the early 1930s, a crisis had crescendoed in cosmology. At a January 1930 Royal Astronomical Society meeting, de Sitter commented on the inability of existing cosmological models to reflect the observed universe. Eddington, thinking out loud, responded the problem might be that only static solutions have been sought.<sup>105</sup>

In fact, there were only two viable static options currently available. The first was Einstein's universe, but it had "mass but no motion." Therefore, it couldn't account for the velocity-distance relation. The second was de Sitter's universe, but it had "motion but no mass." Therefore, it couldn't account for the universe's observed mass.

Shortly after the January meeting, Lemaitre brought his nonstatic solution to the attention of Eddington, his former professor. Historian Norris Hetherington notes the response:

Eddington immediately recognized in Lemaitre's paper, on a homogeneous universe of constant mass and increasing radius accounting for the radial velocity of extragalactic nebulae, a solution to the dilemma following from the observational rejection of both static models. De Sitter also praised Lemaitre's ingenious solution.<sup>106</sup>

Although other models were offered around the 1930s as alternative solutions (such as those by E.A. Milne and Fritz Zwicky), Lemaitre's won the day and was also

<sup>105</sup> Norris S. Hetherington, "Hubble's Cosmology," in Encyclopedia of Cosmology (New York: Garland Publishing, Inc.), 292.

<sup>106</sup> Ibid.

given an endorsement by the leading extragalactic-nebulae expert Hubble. In 1931, Lemaitre provided a modified and expanded version of his theory.

### An Optical-Doppler-Redshift-Theory Problem

In addition to being able to account for Hubble's redshift-distance relation, Lemaitre's expanding universe and space-expansion redshift theory avoided a significant problem that the optical-Doppler redshift theory faced: superluminal velocities. For instance, Einstein's Special Relativity Theory had posited that nothing could travel at or beyond the speed of light since such an object would achieve infinite mass at the speed of light, which would require an infinite force. But Slipher's anomalous large redshifts posed the possibility that astronomers might detect large enough redshifts that would equal or exceed light speed when interpreted through Doppler redshift theory. Furthermore, the velocity-distance relation, which was based on the Doppler redshift theory, seemed to indicate that the further celestial phenomena receded, the more they would increase in velocity. It wasn't difficult to see that if there existed receding objects beyond the observable universe, they might already be traveling at superluminal speeds. And even if this wasn't the case, the velocity-distance relation posed the possibility that the observed receding objects eventually might exceed light speed. In any event, there appeared to be a potential conflict with relativity theory.

### A Relativistic-Redshift-Formula Solution

One solution to this problem appears to have been the modification of the classical Doppler-Redshift formula. This formula stated  $V = Z \times C$ , where  $V$  is the radial velocity of the receding object,  $Z$  is the shift in wavelength divided by the

normal unshifted wavelength, and C is the speed of light. According to this equation, if the observed shift in wavelength equalled or surpassed the normal unshifted wavelength, then Z would be equal to or greater than one, which would mean that V would be equal to or greater than the speed of light.

At some point, the classical formula was modified due to the increasing observation of larger redshifts. The solution was labelled the Relativistic Redshift Formula and expressed by the mathematical formula  $V = [(Z + 1)^2 - 1/(Z + 1)^2 + 1] \times C$ . Since the numerator of the formula's fraction was guaranteed to always be less than the denominator regardless of what value was inserted for Z, the velocity of any redshifted object would always be less than the speed of light.

### A Relativistic-Redshift-Formula Problem

Although the relativistic redshift formula seemed to solve the superluminal speed problem, unfortunately it posed a new problem: the relativistic redshift formula, which is based on special relativity, is not applicable to far distances since they operate on general relativity. This new problem has been recently articulated by contemporary cosmologists Sten Odenwald, Richard Tresch Fienberg, and Edward Harrison.<sup>107</sup>

These three cosmologists point out that special relativity is founded on a different type of geometry than is general relativity and, therefore, which formula is used for what calculation is crucial. For instance, special relativity is based on a perfectly flat and static space-time that isn't affected by matter or energy. This means that the classical and relativistic Doppler formula can be used for small redshifts no

<sup>107</sup> Sten Odenwald and Richard T. Fienberg, "Galaxy Redshifts Reconsidered," Sky & Telescope (February 1993): 31-35; Harrison, Cosmology, see chapter "Redshifts," 231-248.

larger than .2. On the other hand, general relativity incorporates curved space-time and thus gravitational fields become geometric curvatures of space-time.

Consequently, when using high redshifts to make calculations, the classical and relativistic Doppler formula's are inappropriate. Instead, the cosmic scaling factor formula, which measures the increased expansion size of the universe, should be used.<sup>108</sup> By using this formula based on general relativity for redshift originating billions of light-years away, there is no violation of special relativity's light speed.

Odenwald and Fienberg explain it this way:

Does this mean that special relativity is wrong? No, but just as Newtonian physics gives way to special relativity for describing high-speed motion, so too does special relativity give way to general relativity on very large scales. General relativity relegates special relativity's flat and static space-time to a microscopic domain within a larger geometric possibility. In a small region of space-time we can still define motion as we always have, because space for all practical purposes has retained a flat, static geometry. But the special-relativistic Doppler formula cannot be used to quantify the velocity of high-redshift galaxies and quasars, because these are so far away that the curvature and expansion of space-time between us and them becomes important.<sup>109</sup>

### The Comoving Coordinate System

In the late 1920s, mathematicians Howard P. Robertson and A.G. Walker provided an explanation for how space expanded with reference to large-structures of the universe.<sup>110</sup> Robertson's and Walker's solution involved the comoving coordinate

<sup>108</sup> For the full formula, see the next section directly below entitled "The Comoving Coordinate System."

<sup>109</sup> S. Odenwald and R. T. Fienberg, 1993, Sky & Telescope, 34.

<sup>110</sup> Robertson had proposed his own expansion model in 1929. Relying entirely on a priori reasoning instead of starting from some putative physical grounds as did Einstein and de Sitter, he developed a model that was perfectly homogenous and

system, which was a conceptual aid they devised. The comoving coordinate system posited that the largest structures of the universe, which were thought to be galaxies at this time, were at absolute rest with reference to their relative space. Within their relative space there was peculiar motion, but galaxies themselves did not move through space; rather, they remained "fixed" to their local space. However, the space between these structures did expand, which resulted in galaxies becoming farther and farther apart. This gave the appearance of galaxies comoving through space, even though they actually did not move through space. Furthermore, they posited that space expansion would also cause redshifting. Therefore, a redshift-distance relation would occur.

Robertson's and Walker's comoving coordinate system solved the superluminal problem. Since galaxies (i.e., spiral nebulae) were not moving through space as the Doppler redshift theory implied, calculated redshift velocities were free to exceed the speed of light since no object was actually travelling at such velocities. Rather, redshifts indicated how much the universe had expanded since the celestial phenomena emitted their light, which could be calculated by the formula  $Z = (R_0/R) - 1$ , where  $R$  is the scaling factor value at the time of emission and  $R_0$  is the value at the time of reception. Thus, there was no superluminal problem.

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isotropic. In addition, based on the assumptions of isotropy and modesty, Robertson claimed there wasn't a center of the universe. In fact, both Robertson and Lemaitre were against the Doppler interpretation because it made the earth the center of the universe, which contradicted relativity theory. See Howard P. Robertson, "On the Foundations of Relativistic Cosmology," Proceedings of the National Academy of Science 15 (1929): 822-29, reprinted in Cosmological Constants: Papers in Modern Cosmology, eds. Jeremy Bernstein and Gerald Feinberg, 68-76 (New York: Columbia University Press, 1986.)

### Fritz Zwicky

In 1929, Fritz Zwicky, who was a physicist at the California Institute of Technology, proposed a static cosmological model. In this model, he proffered a new redshift theory which suggested that redshifts might be caused due to "gravitational drag" by matter in space on light quanta. His model and redshift theory, however, lost out to Lemaitre's expanding universe and space-expansion redshift theory.

### Evaluation

Based on the above historical account, cosmologists had good and compelling reasons for accepting space-expansion redshift theory and, consequently, relativistic-expansion theory. For instance, one reason for accepting space-expansion redshift was that it didn't possess the superluminal speed problems that the optical-Doppler redshift theory did. A second reason was that it could also account for the observed redshift-distance relation. A third reason was that there was no other equally competing redshift theory. Although Fritz Zwicky did posit an alternative redshift theory which adduced that redshifting was the result of gravitational drag by interstellar matter on light, it was problematic for at least three reasons. First, the 1887 Michelson-Morley experiment seemed to rule out that interstellar matter - if any existed - had any effect on propagated light. Second, since Einstein's relativity theory had postulated that the speed of light was invariant in free space, this seemed to further indicate along with the Michelson-Morley experiment that interstellar matter wouldn't affect the speed of light and, consequently, its wavelength. Third, cosmologists believed that if there existed any interstellar medium through which celestial light passed on its way to Earth, the blurring of spectral lines would result. Since they didn't find any corresponding

spectral-line blurring, it was reasonable to conclude that if there was any interstellar medium or matter, it did not affect starlight wavelength.

Of course, it might be objected that early twentieth-century cosmologists did not have good and compelling reasons to abandon the optical-Doppler redshift theory for the space-expansion redshift theory. For instance, although the Doppler redshift theory faced the superluminal speed problem, the relativistic Doppler formula solved it. Therefore, the optical-Doppler redshift theory didn't possess a superluminal speed problem. Furthermore, if it might now be claimed that it was incorrect for cosmologists back in the 1930s to apply the relativistic Doppler formula to the redshift-distance relation due to the problem of applying Special-Relativity-Theory formulae to General-Relativity-Theory space-time, this objection is problematic since it is unclear whether cosmologists back then realized this inconsistency. If they weren't aware, then it would be inappropriate to hold them accountable to the present contemporary understanding. Therefore, the objection goes, if they did not perceive this difficulty, then it is questionable whether there was any good and compelling reason to abandon the optical-Doppler redshift theory and adopt the space-expansion redshift theory.

Although the above objection makes some interesting points, it shouldn't be overlooked that by the early 1930s cosmologists perceived they were facing a crisis since both the optical-Doppler redshift and static cosmological theories were unable to account for the mass and motion problems. When leading cosmologists became aware of Lemaitre's relativistic-expansion cosmological theory and its space-expansion redshift theory, they realized Lemaitre had provided a solution which could both account for the observational data and resolve the current cosmological crisis. Furthermore, the Robertson-Walker comoving coordinate system also supported

Lemaitre's solution. Therefore, it can be concluded that cosmologists had good and compelling reasons for making the change in both redshift and cosmological theory.

### Conclusion

In this chapter, the reasons for the cosmological community's adoption of the initial optical Doppler and subsequent space-expansion redshift theories as well as relativistic-expansion theory by the early 1930s have been examined. It was concluded that these reasons were good and compelling, given the scientific knowledge and options available to them.

This conclusion, however, does not negate this study's thesis since it states that if some cosmologists start anew today given the current cosmological crisis, it would be a mistake today for such cosmologists to assume that any new cosmological theory would have to explain expansion rather than nonexpansion of the universe. Therefore, it still needs to be argued that such an assumption would presently be a mistake.

## CHAPTER IV

### REDSHIFT-DISTANCE DIFFICULTIES, HUBBLE LAW INVALIDATION, AND ALTERNATIVE REDSHIFT THEORIES

In order to show that it would be a mistake for contemporary cosmologists starting anew to assume any new cosmological theory would have to explain expansion rather than nonexpansion of the universe, it first is necessary to delineate the reasons cited for assuming expansion. Second, once these reasons are articulated, they then need to be examined to see if they are good and compelling. This chapter will pursue both of these tasks, although the second one will be further discussed in the following chapter.

#### Current Reasons Cited for Assuming Expansion

There currently appears to be only three reasons cited for assuming the expansion of the universe, which all rely on spectral redshifts and, interestingly, were the ones used to change from a static to a relativistic-expansion cosmological theory: (1) the redshift-distance relation, (2) the Hubble law, and (3) the space-expansion redshift theory.

The common citation of the first two reasons for assuming expansion rather than nonexpansion is exemplified by the following quotation:

All of cosmology is based on a single fact. The spectra of galaxies contain red shifts that are proportional to their distances...These red shifts are commonly referred to as Doppler shifts due to the recession of the galaxies, which is why we say the universe is expanding....This

law [the Hubble law]...is clear evidence that the universe is expanding uniformly and has no center.<sup>111</sup>

Although redshifts are commonly referred to as Doppler shifts as is stated in the above quotation, cosmologists are aware that redshifts are to be interpreted via the space-expansion redshift theory for distances greater than 30,000 kilometers.<sup>112</sup>

Cosmologist Edward Harrison explains:

Astronomers in the early 1920s thought that Doppler redshifts were the same as expansion redshifts. Rather curiously, the habit of referring to expansion redshifts as Doppler redshifts has survived and is now widespread. Cosmologists feel compelled to use this inexact terminology in popular literature (otherwise, few people would know what they were talking about), and astronomers even catalogue the recession velocities of galaxies by simply multiplying each redshift by the velocity of light [i.e., the classical Doppler formula]....Professionals know what they are doing and therefore avoid the pitfalls that by a misuse of words they have unfortunately prepared for others. The truth is that expansion redshifts are totally different from Doppler redshifts....<sup>113</sup>

Thus, it is the space-expansion redshift theory that is applied to the redshift-distance relation, which itself is then cited as a reason to assume expansion of the universe. In this way, therefore, space-expansion redshift theory has been seen as a good and compelling reason to assume the universe is expanding and, consequently, that expansion cosmological theory should be adopted.

<sup>111</sup> Seeds, Michael A., Horizons: Exploring the Universe, 3d ed. (Belmont, California: Wadsworth Publishing Co., 1989): 314-5.

<sup>112</sup> 30,000 kilometers is approximately how far it is to the center of Earth's own galaxy, the Milky Way. Compared with the size of both the observed and total universe, this distance is very small.

<sup>113</sup> Edward R. Harrison, Cosmology: The Science of the Universe (Cambridge: Cambridge University Press, 1981): 236.

## Good and Compelling Reasons?

The question that now needs to be asked is whether the redshift-distance relation, the Hubble law, and the space-expansion redshift theory presently provide good and compelling reasons for assuming that any new cosmological theory would have to assume expansion rather than nonexpansion of the universe. An answer to this question will now be explored.

### Redshift-Distance-Relation and Hubble Law Difficulties

Although it is often stated that the redshift-distance relation and Hubble law are strong evidence that the universe is expanding, both face serious problems, which raises doubt as to how good and compelling they currently are. Below are several reasons for this analysis.

#### Distance Difficulties

Distance measurements are absolutely essential for establishing the validity and reliability of the redshift-distance relation and the Hubble law. Unfortunately, astronomical distances are extraordinarily difficult to measure, as Harrison explains:

A main theme in the history of twentieth-century cosmology has been the progressive and often bewildering decline in the value of the Hubble term as determined by astronomers. The reason for this is the extraordinary, almost unbelievable, difficulty of measuring the distances of remote extragalactic systems.<sup>114</sup>

John Maddox, editor of Nature, agrees.<sup>115</sup>

<sup>114</sup> Harrison, Cosmology, 209.

<sup>115</sup> John Maddox, "More Muddle Over the Hubble Constant," Nature 376 (27 July 1995): 291.

Six of the many problems astronomers face in trying to calculate cosmological distances will be briefly discussed.

First, cosmological distances are not clearcut distances from one point to another.<sup>116</sup> Cosmologist J.D. North describes these distances as relative comparisons rather than absolute linear quantities. Part of the difficulty is that all astronomical objects are perpetually moving in many complicated ways and, consequently, any two given bodies may be at different distances from each other at different times.

Second, various cosmological concepts of distance lead to many different ways to measure distances, all of them indirect, some of them extremely indirect. This leads to distance discrepancies among cosmologists. Each method of measuring seems to have its own terminology and each stems from a particular concept of distance. Concepts of distance, in turn, are tied to the astronomer's view of the universe, which entails various presuppositions about the unknown reaches of outer space. Furthermore, astronomers deal with a plethora of distance-related concepts that mix the abstract with the concrete. They not only have difficulty relating data and theory to numerical distances, but they have to decide which corrections to make on data. And corrections tend to rest heavily on the underlying cosmological theory.

Third, distance measurements are further complicated by all the factors involving starlight, such as luminosity, and by different logarithmic scales of the magnitude of starlight. Such factors raise questions such as the following: When was the light emitted? From where? In what direction? At what rate did it fall off or gradually extinct? Why? How did the light's position relative to other objects change? How does general relativity affect distances, positions, and light trajectories? What

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<sup>116</sup> J. D. North, The Measure of the Universe (Oxford: Clarendon Press, 1965): 337-44.

events happened simultaneously? How is simultaneity defined? The answers to such questions influence distance determination.

Fourth, since distance measurements rely heavily on extrapolation from what is observed at nearby distances to what is billions of times more distant, it is important for astronomers to work on the assumption that the universe is homogeneous and isotropic - an assumption that is currently questionable based on current observation. The processes, objects, patterns, laws, types, and chemical compositions that exist billions of light-years from us are quite similar, they hope, to what can be observed in our own galaxy. However, major research on the large-scale structure and processes of the universe cast doubt on the cosmological principle.

The fifth problem astronomers face in trying to calculate cosmological distances involves the "cosmological distance ladder," which is a methodology that has been yielding very uncertain and inconsistent results. The degree of uncertainty increases with the distance from earth and the amount of extrapolation.

Astronomers can measure stars and galaxies near earth with greater accuracy than they can measure the very distant astronomical objects which better fit their criteria for determining the Hubble constant. In order to measure far distances, they have established a "distance ladder" whereby they extrapolate far distances from "yardstick" measurements of nearby stars and galaxies.

The one exception to the distance ladder is the redshift, which is believed to be the only method that can measure the farthest distances in the universe. Wherever the distance ladder can't reach, a velocity-redshift is obtained and plugged into the Hubble formula with a particular Hubble's constant (whose value is still hotly debated and differs by a factor of two - and even three by some cosmologists' estimation) to obtain

a distance. Furthermore, such a use of redshifts is based on the assumption that the universe is expanding - an assumption that this study is investigating.

Although there are several "ladder" distance-measuring methods used by astronomers, three will be specifically discussed: parallax, Cepheid variable stars, and supernovae.

The first method is parallax. Parallax, or triangulation to the surveyor, is basically a geometric-trigonometric method of measuring distances to stars within about 300 light-years. Unfortunately, this method has very limited range. For instance, it is 30,000 light-years just to our own galaxy's center, much less to galaxies which are supposed to be expanding with space.

Furthermore, the parallax method is not always so straightforward and uncomplicated. For instance, there are several different types and variations of parallax methods. One type, called spectroscopic parallax, has been used to calibrate Cepheid variable stars in order to make formulae to extrapolate distances using them.<sup>117</sup> It appears that Ejnar Hertzsprung used it in his original Cepheid calibration.<sup>118</sup> However, astronomy author Michael Seeds cautions:

This method is not very accurate because there is some uncertainty in Figure 8-10 [the location of stars classed by their luminosities on the Herzsprung-Russell diagram of star types and temperatures] due to the individual differences between stars. Consequently, when we classify a star's spectrum, we can't be sure of its exact absolute magnitude. It might be a little brighter or fainter than the diagram predicts. If the star is just 1 magnitude fainter than we expect, the distance we calculate is 58 percent too large. Although this method is not very accurate,

<sup>117</sup> Smith, The Expanding Universe, 76.

<sup>118</sup> Michael J. Crowe, Modern Theories of the Universe from Herschel to Hubble (New York: Dover Publications, Inc., 1994): 238.

spectroscopic parallax is often the only method available for measuring distance.<sup>119</sup>

In addition to the above problem, the use of the Hertzsprung-Russell diagram generally involves assumptions about stellar evolution and deductions from limited data about the internal composition and processes of stars.

The second method of measuring distances is by Cepheid variable stars.

Cepheids are variable stars that periodically-cyclically gradually increase and then decrease in brightness. They are usually found in spiral galaxies, and it is believed that there is a direct (and traditionally invariant) relationship between the period (i.e., time of a variation cycle) of a Cepheid and its absolute magnitude. (For non-variable stars, there presently is no way to ascertain absolute magnitude). The apparent magnitude is also then measured, which is approximately the amount of brightness detected on earth.

Because the distance to nearby Cepheids is believed to be known by parallax, formulae have been devised to calibrate Cepheids for long-distance measurements. This calibration relates a star's absolute magnitude, apparent magnitude, and distance from earth. Now if the cosmological principle is applied to Cepheids (i.e., if it is assumed that all Cepheids in the universe abide by the calibrating formulae), Cepheids can serve as "standard candles" by which reliable distances can be extrapolated for galaxies near these distant Cepheids.

However, some scientists seriously question such use of Cepheids. Harvard astronomers Press and Kirshner don't agree that the brightest galaxy in each cluster is as bright as in every other cluster; rather, they suspect that galaxies vary systematically in brightness, which calls into question the assumption that all Cepheids

<sup>119</sup> Seeds, Horizons, 158-9.

produce the same effects everywhere.<sup>120</sup> Maddox further states there are difficulties determining distances to Cepheids as well as in determining and interpreting variations in Cepheid brightness.<sup>121</sup>

Ken Croswell, an astrophysicist and frequent writer of science articles and books, laments that for most of this century Cepheids have been seen only in nearby galaxies, which means Cepheid data cannot reveal the Hubble constant.<sup>122</sup> He hopes that Hubble Space Telescope data will finally check the use of Cepheids as a fundamental yardstick. He also shows concern that "differing chemical composition among Cepheids may alter their luminosities, which would compromise our ability to gauge distances by using Cepheids."<sup>123</sup> Likewise, David Eicher hopes new data will enable astronomers "to check the calibration of the Cepheids, and try to end the disputes over where they are, what they are like, and how to interpret their brightness variations."<sup>124</sup>

The third distance-measuring method involves supernovae. Allan Sandage, a former student of Hubble and head of a team which disagrees with Wendy Freedman on the reliability of Cepheid data and their interpretations over long distances, determines distances primarily by studying supernovae and the shells they eject when they explode. His method uses the shell's line-of-sight expansion speed, determined by the Doppler effect, plus inferences from changes in brightness and temperature to

<sup>120</sup> Sam Flamsteed, "Crisis in the Cosmos," Discover (March 1995): 77.

<sup>121</sup> Maddox, 27 July 1995, Nature, 291.

<sup>122</sup> Ken Croswell, "How Far to Virgo?" Astronomy (March 1995): 50.

<sup>123</sup> Croswell, K., 1995, Astronomy, 47.

<sup>124</sup> David J. Eicher, "Candles to Light the Night," Astronomy (September 1994): 39.

determine distance.<sup>125</sup> Thus, Sandage's supernovae-distance methods depend heavily on inferences about the nature of supernovae and redshift-velocity measurements.

The sixth problem astronomers face in trying to calculate cosmological distances is that they are unable to determine each term of the Hubble law independently from the other two terms. Since the only data from far away celestial phenomena is spectral redshifts, it is difficult to determine either the Hubble constant or distances in order to figure out a missing term in the Hubble formula. For instance, assuming redshifts do indicate recessional motion, astronomers might calculate a velocity. But the Hubble formula states that the velocity equals the Hubble constant multiplied by the corresponding distance. Since distances are uncertain and the Hubble constant is presently believed to be between 30 to 100 km per second per megaparsec, it is difficult to determine the values of these two terms with precision.

Furthermore, not knowing the Hubble constant value affects many other calculations. Astronomers Wendy Freedman and NASA Barry F. Madore have written a list of reasons why measuring the expansion rate of the universe (i.e., the Hubble constant) is crucial to cosmology:

Not only does it test various cosmological models, but it also is required to determine many intrinsic properties of galaxies and clusters of galaxies, such as their masses, luminosities, and sizes. Finally, clocking the universe's expansion bears strongly on the early growth of

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<sup>125</sup> Roth, J. and J. R. Primack, 1996, Sky & Telescope, 22; Saul Perlmutter, "Weighing the Universe with Supernovae," insert in Roth & Primack, 1996, Sky & Telescope, 27; Ray Jayawardhana, "The Age Paradox," Astronomy (June 1993): 43; Allan Sandage and G. A. Tammann, "Steps Toward the Hubble Constant. X. The Distance to the Virgo Cluster Core Using Globular Clusters," Astrophysical Journal 446 (10 June 1995): 1-10.

galaxies and larger-scale structures and on the formation of the earliest chemical elements.<sup>126</sup>

Thus, the above considerations seem to indicate that distances for extra-galactic celestial phenomena become increasingly uncertain the farther they appear to exist from earth. Therefore, the redshift-distance relation and the Hubble law, which depend on distances considered far and very far from Earth for their validity and are used to justify assuming expansion rather than nonexpansion of the universe, have significant margins of error and are not as well-confirmed as sometimes is claimed.

### Hubble Law Difficulties

Other problems also exist with the Hubble law, which is essentially an expression of the velocity-distance relation initially determined by Hubble. The Hubble law is often cited as evidence for an expanding universe. Recently, however, the Hubble law is being called into serious question by some as a result of current data. In addition, others have noted significant problems in Hubble's original data, which led to the establishing of the velocity-distance relation and the Hubble law. Several of these Hubble law problems will now be discussed.

First, a team of astronomers, who have been utilizing the infrared astronomical satellite (IRAS) to check for infrared velocities, distances, and magnitudes of stars, galaxies, and galaxy clusters, have concluded the Hubble law is empirically invalid. Furthermore, they consider the data used in studies which assume the Hubble law to be invalidated by biased sampling of galaxies. Some of the problematic results of such

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<sup>126</sup> Wendy L. Freedman and Barry F. Madore, "Measuring the Hubble Parameter with HST," insert in Roth and Primack, Sky & Telescope, January 1996, 24.

biases are noted by I.E. Segal, who is the head of the team of astronomers managing the IRAS:

Textbook presentations of the Hubble law typically report measurements on bright cluster galaxies. The samples are often subjectively constituted, and the catalog of Abell (2) from which sample clusters are often taken, explicitly assumes the Hubble law in its selection criterion. The sample of Hoesel *et al.* (3), which provides one of the major supports for the Hubble law, consists of 116 galaxies drawn entirely from the Abell catalog.<sup>127</sup>

Segal expresses regret that other studies have assumed the Hubble law without considering any alternative redshift-distance law or making testable predictions to verify it. He boldly concludes:

The rather definitive invalidation of the Hubble law by the present analysis renders dubious the empirical implications of theoretical studies based on the assumption of the Hubble law. The conclusions of many recent studies using this assumption, often in conjunction with the unsubstantiated and empirically somewhat contradicted (by direct anisotropy observations) assumption of spatial homogeneity in the low-redshift regime, may be entirely fallacious.<sup>128</sup>

Second, German astronomer Edmond Giraud, in an article entitled "The Price to Keep the Hubble Constant - Constant," asserts that important parameters of major studies concerning the Hubble law have been biased. He states that galaxy samples "are unfair representations of the real world and that the distance indicators are only loosely correlated with absolute magnitudes."<sup>129</sup> He further adds that discrepant data is dropped out of reported results, model parameters are forced to obtain desired

<sup>127</sup> I.E. Segal and J. F. Nicoll, "Apparent Nonlinearity of the Redshift-Distance Relation in Infrared Astronomical Satellite Galaxy Samples," Proceedings of the National Academy of Science 89 (December 1992): 11669-72.

<sup>128</sup> *Ibid.*, p.11671.

<sup>129</sup> Edmond Giraud, "The Price to Keep the Hubble Constant - Constant," in New Ideas in Astronomy, eds. F. Bertola, J. W. Sulentic, and B. F. Madore (Cambridge: Cambridge University Press, 1988):327.

conclusions, and the dispersions of luminosity indicators contain systematic errors.

Giraud concludes that "the results are totally model dependent and imply that all samples are unfair representations of the real world."<sup>130</sup>

Third, astrophysicist Steven Weinberg notes that Hubble's data was too sparse and too nearby to reliably conclude the Hubble law. He states:

[Hubble's conclusion in 1929] was that there is a "roughly linear relation" (i.e., simple proportionality) between velocities and distances. Actually, a look at Hubble's data leaves me perplexed how he could reach such a conclusion - galactic velocities seem almost uncorrelated with their distance, with only a mild tendency for velocity to increase with distance. In fact, we would not expect any neat relation of proportionality between velocity and distance for these 18 galaxies - they are all much too close, none being farther than the Virgo cluster. It is difficult to avoid the conclusion that...Hubble knew the answer he wanted to get.<sup>131</sup>

In other words, Hubble's sample was essentially of galaxies that today are not believed to be far enough away from Earth to be affected by space expansion. Therefore, even if they followed a redshift-distance relation, this would not be evidence for the expansion of the universe.

Fourth, Hubble lacked objectivity and uniform criteria in his designation of magnitudes, which he used to calculate distances incorporated into the Hubble law. North observes that "the great difficulty here is that observing in an unconsciously selective manner will lead the observer into the mistake of favouring sources which are progressively more luminous the greater their distance."<sup>132</sup> He further adds:

Shane and others investigated Hubble's measurements of twenty years before and found that not only were the limiting magnitudes different for different types of galaxy, but that they differed from plate to plate

<sup>130</sup> Ibid., 328.

<sup>131</sup> Weinberg, The First Three Minutes (New York: Basic Books, 1977): 25-6.

<sup>132</sup> North, 246.

and even from one place to another on any given plate. These authors estimated the mean galactic extinction towards the poles at 0.46 magnitudes - nearly twice Hubble's value."<sup>133</sup>

Fifth, North also points out that there was a lack of scepticism in the 1930s toward extra-galactic astronomy, which partly may have resulted from there only existing one telescope in the world capable of making such long distance observations - and Hubble was the one who had access to it. He further states that "whatever the explanation, criticism of the empirical value of the Hubble factor was not often forthcoming, and it appears at times that astronomers were more concerned with bringing the rest of astrophysics into line with the parameter in Hubble's Law than the other way about."<sup>134</sup>

Sixth, Hubble made systematic errors in estimating luminosities of Cepheid variable stars and misidentified H II regions as stars (i.e., regions of predominantly ionized hydrogen in interstellar space). In fact, he thought the H II regions were the brightest stars in galaxies beyond the Local Group. These errors were of importance as they influenced the calibration of Cepheids, which were indicators of distances. Indicators of extragalactic distances farther out than the nearby galaxies and clusters were built on extrapolation of distances to Cepheids.<sup>135</sup>

Seventh, Hubble made errors in his use of "correction factors," which he applied to his redshift and distance data.<sup>136</sup>

<sup>133</sup> Ibid., 247.

<sup>134</sup> Ibid., 228-9.

<sup>135</sup> Ibid., 148.

<sup>136</sup> See North, 146-8, 340, 344.

Eighth, Hubble's use of Cepheid variable stars to determine distances is questionable because of the uncertain reliability of the method, apart from particular errors in using Cepheid data that Hubble probably made. In fact, finding magnitudes, and thus distances from Cepheids, is still problematic today.<sup>137</sup>

Although the validity of Hubble's velocity-distance relation is seriously questionable, this does not affect whether contemporary cosmologists have new and better data which confirm the Hubble law. Although there is newer and better data available today, as noted above at least some of this data appears to disconfirm the Hubble law.

### Discordant-Redshift Dilemmas and Quasar Quandaries

The discovery of quasars in the 1960s had a jarring impact on astronomy. A popular textbook makes the following observation concerning the detection of quasars:

Quasars (also called quasi-stellar objects, or QSOs) are small, powerful objects that seem to lie far away, and astronomers are coming to think of them as very powerful, very distant peculiar galaxies....the discovery of quasars in the 1960s revolutionized astronomy. The objects were so unbelievable that scientists had to re-examine the validity of the most basic natural laws....The discovery of quasars shocked astronomers. The objects were unlike anything that had been discovered before. They seemed to lie far beyond the galaxies and to be 10 to 1000 times more luminous.<sup>138</sup>

Today, over seven thousand quasars have been detected.

There also is a problem with discordant redshifts, which many galaxies appear to exhibit. A discordant redshift occurs when a group of galaxies appearing to be

<sup>137</sup> For a fuller treatment, see "Questionable Distance Measurements" later in this chapter.

<sup>138</sup> Seeds, Horizons, 301.

associated together at the same distance from earth has one or more members with a significantly different redshift than the others. This also occurs when a high-redshift quasar appears associated at the same distance with lesser-redshifted galaxies or other disparately-shifted quasars. According to both the redshift-distant relation and the Hubble law, such discordant redshifts should not exist, so this poses a problem.

An example of a discordant galaxy redshift is Stephan's Quintet. This tight cluster of five galaxies was first discovered in 1877 by Edouard Stephan, director of the Marseilles Observatory in France, and it has been closely scrutinized by astronomers worldwide ever since. Stephan's Quintet lies about 1/2 degree south-southwest of the large, bright spiral galaxy NGC7331. It consists of two elliptical and three spiral galaxies intertwined in faint clouds of nebulosity, implying they are all members of the same group. In 1961, astronomers discovered one member had a much smaller redshift than the others. This lower-shifted galaxy appears to be receding at about 800 km per second, while the other four velocities are approximately 6,000 km per second. According to Hubble's law, their distances are 35 million and 250 million light-years, respectively, (assuming a Hubble constant of 75 km per second per megaparsec) which contradicts other observation that they are a tight cluster.

Astronomers have suggested numerous explanations to preserve both the redshift-distance relation and the Hubble law in the case of Stephan's Quintet and other galaxy-galaxy discordant redshifts:

But a few analyses in the 1960's and '70's suggested that systems with discordant redshifts are too numerous to explain by chance....all the objects in these associations are at the same distance, and part of the redshift for some must be unrelated to the velocity of recession.<sup>139</sup>

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<sup>139</sup> Sky & Telescope, "Redshift Debate Rages On," Sky & Telescope (September 1988): 234.

Geoffrey Burbidge, an astrophysicist at the University of California, San Diego, in a 1988 Sky and Telescope article, picked out three examples of noncosmological redshifts which were convincing evidence to him. Two examples were galaxy-quasar associations. The third was a pair of galaxies NGC7603 and its companion, connected by a luminous bridge, but having very different redshifts. The small companion galaxy had a redshift showing a velocity of 8,300 km per second in excess of the redshift-derived velocity of NGC7603. There has been no evidence that the two galaxies are not at the same distance.<sup>140</sup>

An interesting sociological development appears to have occurred in the scientific community over the issue of quasars, which involves astronomer Halton Arp. Arp is very well credentialed. He received a B.A. from Harvard and a Ph.D. in astrophysics from the California Institute of Technology. He was a member of the Caltech faculty for 23 years, and worked out of the Mount Wilson and Las Campanas Observatories.

Over the past two decades, however, Arp has been treated as an outsider apparently due to his hypothesis concerning quasars. In March, 1966, at Caltech, Arp first presented evidence that some quasars were associated with nearby galaxies. One astronomer in the room was heard to disparagingly remark, "Well, this will be the shot that was heard around the room."<sup>141</sup> The opposition to Arp's findings seems to hinge upon their result for the Hubble law:

The Hubble law is the cornerstone of all modern cosmology. It is the foundation of the theory that says the Universe has been expanding

<sup>140</sup> Geoffrey Burbidge, review of Quasars, Redshifts and Controversies, by Halton Arp, in Sky & Telescope (January 1988): 42-43.

<sup>141</sup> Halton Arp, Quasars, Redshifts, and Controversies (Berkeley: Interstellar Media, 1987), 7.

since a primordial Big Bang 15 to 20 billion years ago. Any astronomer who questions the Hubble law is committing heresy....This [quasar] dilemma was so puzzling that some astronomers had the audacity to say the Hubble law was wrong.<sup>142</sup>

Furthermore, if Arp was correct, then this affected the life work of many astronomers:

If you believe in the Hubble law, there is no other way to explain these anomalous red shifts. As Caltech astronomer Jesse Greenstein explains, "If there is anything to Arp's observations, then everything is up for grabs!" Indeed, if Arp is right, we must admit to gaping holes in our understanding of the Universe. Needless to say, this is not a comforting prospect to the typical astronomer, who has based his life's work on ideas such as the Hubble law....Traditional astronomers are aghast at the idea that undiscovered laws of nature might be at work in the Universe.<sup>143</sup>

But in spite of the potentially unsettling results, Arp continued to make his case, even taking on the Hubble law as well as calling for scientific openness to new understandings of the universe:

It is of profound importance to recall now that for a number of classes of galaxies and extragalactic objects there was never any shred of evidence that they obeyed a Hubble relation. Sb galaxies are actually the only kind of bright galaxies to obey an accurate Hubble relation. The assumption that other kinds of objects obeyed a redshift-distance relation sprang simply from the feeling that if one kind of object did, all objects must do so....It would seem obvious that if a scientist only reasons deductively from known laws then he or she can never do more than recover those laws, and will never discover anything fundamentally new....it may sometimes be that not to know one thing that is wrong could be more important than knowing a hundred things that are right.<sup>144</sup>

Realizing the various implications of Arp's findings, it is understandable why there might be resistance instead of the usual characteristic scientific openness.

<sup>142</sup> William Kaufmann III, "The Most Feared Astronomer on Earth," Science Digest (July 1981): 80.

<sup>143</sup> Ibid, 117.

<sup>144</sup> Arp, Quasars, 178-9.

Although Arp called for open-mindedness, the immediate response was to deprive him of telescope time, which precluded his further data collecting concerning quasars.

Historian Timothy Ferris recounts this development:

In 1981 the committee allocating Palomar observing time informed Arp by memo that he should not expect to be granted further access to the 200-inch telescope if he persisted in using it to investigate associations between quasars and galaxies. Arp's years of work on discordant redshifts had produced few verifiable predictions, the memo emphasized, and his views had failed to win the support of more than a small minority of astronomers....Sandage came to Arp's defense. He said he felt that Arp's work had some value, especially now that Arp was at last prepared to make an in-depth survey of a swatch of sky large enough for meaningful statistical conclusions to be drawn about the distribution of galaxies and quasars. And Sandage didn't care for the memo. That wasn't the way to treat a senior astronomer, he said. Unswayed, the committee in 1982 sharply reduced the time allocated to Arp on the 200-inch telescope.<sup>145</sup>

Arp recalls:

A number of directors of other observatories as well as other well-known astronomers communicated to the director of my observatory strongly supporting my research and opposing the action of the allocation committee. I challenged members of the committee to debate the actual scientific facts. But none of this prevented the inevitable last act. My observations on the 200-inch telescope at Palomar terminated in 1983, and at Las Campanas in 1984.<sup>146</sup>

Arp subsequently moved to the Max Planck Institute for Astrophysics in Garching, Germany, where he has telescope time that enables him to continually publish new findings on the nature and distribution of quasars and galaxies in relation to their redshifts. He tends at present to think redshifts are primarily functions of the qualitative and quantitative characteristics of the emitting sources; in other words,

<sup>145</sup> Timothy Ferris, The Red Limit: The Search for the Edge of the Universe, introduction by Carl Sagan, (New York: Quill, 1983), 198-99.

<sup>146</sup> Arp, Quasars, 167.

redshifts are not the result of expansion. Many other astronomers are likewise publishing findings on discordant redshifts, which are in agreement with Arp.

Therefore, the above discussion of quasars and other discordant redshifts seem to indicate that there exists significant problems which further challenge the validity of both the redshift-distance relation and the Hubble law.

### Conclusion

The above discussion concerning distance-measurement difficulties, Hubble law discrepancies, and quasar and discordant redshift dilemmas, indicates that the redshift-distance relation and Hubble law are not as well established as has been claimed or thought by many cosmologists. Consequently, they are no longer as good and compelling reasons as they were back in the early 1930s for assuming expansion rather than nonexpansion of the universe.

### Six Alternative Redshift Theories

The third reason cited for assuming the expansion of the universe is the space-expansion redshift theory. In the remainder of this chapter, six alternative redshift theories will be presented, and the following chapter will focus on evaluating whether the space-expansion theory still provides a good and compelling reason to assume expansion rather than nonexpansion of the universe, especially when compared with the six alternative redshift theories.

#### The Intrinsic-Property Redshift Theory

One alternative redshift theory is what can be called the intrinsic-property redshift theory. This theory posits that redshifts are partly or even totally caused by

quantitative or qualitative properties intrinsic to light-emitting celestial phenomena. Depending on the composition of individual stars and collective structures such as globular clusters and galaxies, various redshifted wavelengths are emitted. One example of a possible intrinsic redshift are quasars, as suggested by Arp. Another possible example is redshift quantization. This latter possibility warrants further examination.

While Halton Arp was studying quasars and occasionally discovering "quantization" in quasar redshifts, respected astronomer William G. Tifft at the University of Arizona was finding quantized galaxies and quasars.

Tifft has discovered that galactic and quasar redshift values fall only at certain fixed values and not in between. Therefore, they appear to be quantized. As noted in chapter two of this study, quantization challenges big bang theory and possibly even expansion theory.

Tifft didn't start out doubting the expansion of the universe. At first, he merely observed discrete bands of redshifts, which by 1973 he was calling "harmonic periodicities" and by 1976 "discrete redshift states," then "discontinuities," "asymmetrical distributions," and finally "quantization." Tifft found that redshifts seem to have "preferred values," banding or bunching around multiples of 72 km per second, including the submultiples 36-7 and 24 km per second.

Tifft's early publishing took a turn toward the unusual in a series of five articles correlating redshift with magnitudes in the Coma Cluster.<sup>147</sup> He reported that galaxies

<sup>147</sup>William G. Tifft, "The Correlation of Redshift with Magnitude in the Coma Cluster," Bulletin of the American Astronomical Society 3, no. 3, pt. 1 (August 1971): 391; William G. Tifft, "Redshift Morphology and Integrated Magnitude Relationships in the Coma Cluster," Bulletin of the American Astronomical Society 4, no. 2, pt. 1 (April 1972): 238; William G. Tifft, "The Correlation of Redshift with Magnitude and Morphology in the Coma Cluster, Astrophysical Journal 175, no. 3, pt. 1 (1 August

fall in bands or steps, becoming fainter with increasing redshift. The deviation from the expected random correlation was significant at a probability much less than one percent, and Doppler motion appeared not to exceed 10 km per second. This latter point means that if the universe was expanding, it would be doing so extremely slow. Furthermore, nearly all the highest redshift galaxies in the Coma Cluster were nonellipticals. This was unexpected and remarkably similar to the pattern in the Virgo Cluster where the spiral galaxies showed a distinctly greater redshift than the ellipticals. No known physical mechanisms could explain the pattern, and intrinsic redshift was suggested as the cause.

After publication of his initial Coma Cluster findings, Tifft worked on refining his results statistically. He found that the morphological (i.e., the shape or type of a celestial phenomenon) dependence on redshift and magnitudes was maximum along the direction of the bands of step-like preferred values.

By August of 1972, Tifft had increased his correlation scrutiny to 100 Coma galaxies. The separation of the ellipticals from nonellipticals was significant in both redshift and magnitude, and a more strongly banded structure appeared. He wrote that in the presence of an unexplained intrinsic redshift producing a banded pattern, the mean redshift of a galactic morphological group need not be the same as the Hubble velocity of the cluster. A statistical "power-spectrum analysis" then showed a correlation between banded redshift values and galaxy angular momentum.

Tifft's next two studies showed significant banding in quasars.<sup>148</sup> He then increased the number of galaxies studied and statistically searched for the possibility that random chance was causing the bands; he concluded this wasn't the case.<sup>149</sup> He later found his results to also show the same redshift when using x-ray analysis.<sup>150</sup>

In 1976, Tifft began a series of three articles on discrete states of redshift and galaxy dynamics. He wrote very daring and startling conclusions to one of these papers concerning the expanding universe, general relativity, and quantum electrodynamics:

The predictions [of quantization] made have been verified in virtually all cases and offer alternatives to some very puzzling astrophysical problems: the mass discrepancy problem for galaxies, and stellar rotational peculiarities, to name two major ones....the origin and evolution of galaxies by collapse are also untenable, as are most the cosmological concepts based on the "expanding" universe.<sup>151</sup>

Realizing his conclusions might be rejected due their serious implications, Tifft continued:

In view of all the implications which inevitably follow from the discrete redshift hypothesis, it is not surprising that the idea has met extreme resistance. Nevertheless, a set of intimately related significant correlations involving a massive amount of data exist. Showing that the discrete redshift concept is inconsistent with the "expanding

<sup>148</sup> William G. Tifft, "Redshift-magnitude Banding Among Quasi-stellar Sources," Bulletin of the American Astronomical Society 5, no. 1, pt. 1 (January 1973): 40; William G. Tifft, "Redshift-magnitude Bands, Quasi-Stellar Sources, and Systems of Redshift," Astrophysical Journal 181, no. 2, pt. 1 (15 April 1973): 305-26.

<sup>149</sup> William G. Tifft, "The Definition, Visibility, and Significance of Redshift-Magnitude Bands," Astrophysical Journal 188, no. 2, pt. 1 (1 March 1974): 221-32.

<sup>150</sup> William G. Tifft and M. Tarenghi, "Redshift Dispersion in the X-ray Cluster of Galaxies A1367," Astrophysical Journal 198, no. 1, pt. 2 (15 May 1975): L7-L8.

<sup>151</sup> William G. Tifft, "Discrete States of Redshift and Galaxy Dynamics. III. Abnormal Galaxies and Stars," Astrophysical Journal 211, no. 2, pt. 1 (January 1977): 390.

"universe" or even general relativity or quantum electrodynamics will not eliminate or explain the correlations!<sup>152</sup>

Thus, Tifft attempted to head off any premature discounting of his hypothesis by pointing out (a) the data couldn't easily be ignored since it was massive in amount, and (b) any appeals to expansion theory, general relativity theory, or quantum electrodynamics as criteria by which to discredit the data is inappropriate and still wouldn't provide a consistent explanation for the data.

Tifft continued to find confirmation of his hypothesis based on the work of others. For instance, he was able to use a new information-gathering method after the famous 1981 Fisher-Tulley survey of redshifts, which were detected by radio telescopes that could pick up the 21-cm radio waves that seemed to make it through earth's atmosphere without distortion. The Tully-Fisher galaxies showed sharp periodicities at exact submultiples of 72.45, which matched Tifft's findings of the Coma Cluster based on optical telescopes.<sup>153</sup>

Validation also came from across the Atlantic in 1991. Two Royal Observatory astronomers, B.N.G. Guthrie and W.M. Napier, had previously attempted to prove Tifft wrong concerning quantization of the dwarf galaxies. They initially had found that, contrary to Tifft's hypothesis, quantization was not significant. But then they made corrections for the motion of our own sun relative to the center of the Milky Way Galaxy and discovered the quantization data showed periodicity to be present at a high confidence level of 37.2 km per second, which was a submultiple of

<sup>152</sup> Ibid.

<sup>153</sup> William G. Tifft and W. J. Cocke, "Global Redshift Quantization," Astrophysical Journal 287, no. 2, pt. 1 (15 December 1984): 492-502.

Tifft's basic figure of 72 to 73. They had also used a variety of methods and statistical tests.<sup>154</sup>

Guthrie and Napier had studied all previous literature on quantization and eliminated from their samples any galaxies that had been in previous studies.<sup>155</sup> This risked showing a false lack of quantization, but they wanted a pristine sample. They found that relating redshifts to the center of the Milky Way Galaxy (whether by use of an averaged solar vector or by using a continuum of successive solar vectors) made all the difference in revealing quantization. The hypothesis of Tifft and Cocke that redshift periodicity occurs in the range of 70 to 75 km per second or one of its submultiples was preferred over the null hypothesis (i.e., that redshift distribution is random) at a high confidence level of C~0.997. Further tests showed that periodicity held for spirals, but not for irregulars in a nearby location. A number of science journals took serious note of Guthrie's and Napier's verification of quantization.

Guthrie's and Napier's confirmation of quantization when corrected for the Milky Way Galaxy also supports the possibility that there may be a center of the universe - possibly even our own galaxy. Furthermore, Tifft has pointed out that quantization is also pronounced when measured relative to the cosmic microwave background, which is supposed to be the universal rest frame.

In 1991, Tifft summarized his findings to that point on redshift periodicity and pointed out there appeared to be quantization of time as well as space. Periodicity has also been observed in all the variable stars, quasars, and pulsars. In addition, the visual

<sup>154</sup> B. N. G. Guthrie and W. M. Napier, "Evidence for Redshift Periodicity at Nearby Field Galaxies," Monthly Notices of the Royal Astronomical Society 253 (1991): 533-44.

<sup>155</sup> Ibid., 534.

brightness of blue variables is currently reported to change by a factor of two to six every five to ten years by increasing and decreasing their diameters.<sup>156</sup>

Although Tifft's findings seriously threaten big bang cosmology and potentially expansion theory, there's not a serious outstanding methodological criticism made by other researchers and scientists. Neither is there a reasonable chance that Tifft's findings are statistical flukes.

### The Compton Redshift Theory

The Compton redshift theory is not a new idea. In 1929, just a few months after Hubble's 1929 velocity-distance relation was announced, the highly respected mathematician Fritz Zwicky issued a tactful caution about the scientific community's apparent rush to accept the optical-Doppler redshift theory and apply it to Hubble's redshift-distance relation without considering well enough other possible causes for the observed spectral displacements. He suggested something comparable to the Compton redshift theory that might be the reason for spectral redshifting.<sup>157</sup> Zwicky's caveat may even have been partly responsible for Hubble's adoption of the phrase "apparent velocity" in his publications.

The Compton redshift theory is based on the knowledge, unknown in Hubble's time, that outer space is filled with a plasma composed of about one electron and one proton per 100 cm<sup>3</sup>. (This can be observed at 144-m wavelength radio astronomy). Electrons have enormous kinetic energy, but they lose some of it whenever they

<sup>156</sup> Govert Schilling, "A Curious Tale of Inflatable Stars," New Scientist (25 September 1993): 15.

<sup>157</sup> Fritz Zwicky, "On the Red Shift of Spectral Lines Through Interstellar Space." Proceedings of the National Academy of Sciences 15 (1929): 773-79.

collide with a proton, even though the proton survives in fine shape. Electron energy is replenished by colliding with photons. Although these photons in turn only lose very small amounts of energy, they are redshifted over long distances due to numerous collisions with electrons.

Although Hubble was aware of the Compton -redshift-theory concept, he didn't adopt it since it didn't seem to be able to satisfactorily explain how energy was lost. Therefore, Hubble sometimes remarked that "light may lose energy during its journey through space, but if so, we do not yet know how the energy loss can be explained."<sup>158</sup> But while Hubble acknowledged the possibility of a Compton-like redshift effect, amateur astronomer Grote Reber was beginning a data-collecting venture which would lead him to conclude in 1986 that the Compton redshift theory is the correct explanation for extra-galactic redshifting, not the Doppler nor space-expansion redshift theories.

The historical development leading to Grote Reber's conclusion began in 1935 when he set up a rotating antenna in his backyard after reading history's first article by Karl G. Jansky on radio static from outside our solar system. For the next ten years, Reber was the only person following up on Jansky's observations, which he verified in 1944 after discovering the first radio galaxy. After 55 years as an electrical engineer and radio astronomer, he published his hypothesis on redshifts in the IEEE Transactions on Plasma Science.<sup>159</sup>

<sup>158</sup> Edwin Hubble, The Observational Approach to Astronomy (Oxford: Clarendon Press, 1937).

<sup>159</sup> Grote Reber, "Intergalactic Plasma," IEEE Transactions on Plasma Science, vol. PS-14, No. 6, (December, 1986), 678-82.

In this 1986 article, Reber challenged Hubble's "assumption" of interpreting redshifts as velocities. He quoted Hubble's own acknowledgment of the problems with the velocity interpretation:

The disturbing features are all introduced by the recession factor, by the assumption that red-shifts are velocity-shifts....On the other hand, if the recession factor is dropped, if red-shifts are not primarily velocity-shifts, the picture is simple and plausible. There is no evidence of expansion and no restriction of the time-scale [of the forming of an expanding universe], no trace of spatial curvature and no limitations of spatial dimensions.<sup>160</sup>

Reber pointed out that the Doppler-redshift-theory application was an assumption and that he believed Hubble's interpretation of redshifts was still somewhat of an open question until big bang cosmology was accepted in the mid-1960s. He also quoted writers who admitted the uncertainty of what happens to a lightray that travels 10 billion light-years.

In defense of Hubble, Reber pointed out two main reasons why Hubble couldn't have seriously considered the Compton redshift theory. First, the existence and complexities of interstellar matter, plasmas, and the x-ray background weren't understood then. Second, there may have existed the phenomenon of dissociating oneself from whatever was just discarded as outmoded. For instance, Einstein had assisted in the rejection of space filled with ether. Thus, this had the unfortunate effect that any respectable scientist in Hubble's day didn't consider ether or much of anything else to fill interstellar space. Furthermore, no blurring of spectral lines appeared, which seemed to indicate that interstellar gases were not affecting spectrographic data.

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<sup>160</sup> Hubble, Observational Approach, 66.

"This effectively removed any possibility of light interacting with matter. As such, nothing was left to account for the observed red shifts except relative motion."<sup>161</sup>

Due to new discoveries and better understanding, the above two reasons are no longer valid. Plasma physics is a well-developed branch of physics with its own journals, and there is little doubt that almost all the observable universe is plasma. In fact, it is presently estimated that 99.999 percent of the universe's observable matter consists of plasmas crisscrossed by electromagnetic fields.<sup>162</sup>

Concerning spectral line blurring, John Kierein argues that the Compton effect doesn't need to have this result:

Some authors have objected to the Compton effect interpretation on the basis that such an interpretation would cause blurring of the source or line broadening or not be a percentage shift as the Doppler effect produces....It should be emphasized that the total observed shift is the result of a very large number of scatterings, with a very small red shift per scattering....Because of the very large number of scatterings, the statistics are so good that line blurring need not result....Quantum electrodynamics predicts no significant blurring or line broadening from this effect.<sup>163</sup>

Reber also goes beyond just challenging the velocity-distance relation. He clearly states that the Compton redshift theory eliminates the need for an expanding universe, since it can account for the spectral redshifting just as well as the Doppler or space-expansion redshift theories can. Kierein appears to agree:

This [the Compton effect] produces a shift that is proportional to the wavelength and indistinguishable from a Doppler effect in this respect....All that is required is for there to exist between galaxies a rare gas of a reasonably constant density of free electrons (or other free particles). Such a gas, of completely ionized hydrogen atoms, cannot

<sup>161</sup> Reber, 1986, IEEE Transactions on Plasma Science, 679.

<sup>162</sup> Anthony L. Peratt, "Not With a Bang," The Sciences, (January/February 1990): 28.

<sup>163</sup> John Kierein, "Implications of the Compton Effect Interpretation of the Red Shift." IEEE Transactions on Plasma Science 18, no. 1 (February 1990): 61-2.

be detected spectroscopically except for the red shift it produces. The more distant objects have more free electrons along the line-of-sight, and Hubble's law immediately follows.<sup>164</sup>

Thus, given the current knowledge of interstellar space coupled with the Compton effect, redshifting may be the result of non-expansion causes, which also would exhibit a redshift-distance relation.

### The Interstellar-Medium Redshift Theory

Another possible cause of redshifting is the interstellar medium through which light passes on its way to Earth. The Compton effect, which was discussed above, is a sub-category or one type of interstellar-medium redshifting. But there are others as well.

The science of spectroscopy is based on the scattering of light by matter, which produces emission and absorption spectra.<sup>165</sup> Some types of scattering lower photon energy, others apparently don't.

Concerning the former, it is generally thought that if energy is lost by traveling photons, the loss must come from collisions. There are two main types of collisions in physics, with many subdivisions. An elastic collision is where one object bounces off another with no exchange of energy. If energy is exchanged or transformed, however, then the collision is inelastic. In addition, if radiation is emitted during the impact, the collision is called radiative. Otherwise, it is nonradiative.

When photons are absorbed, sometimes they are re-emitted at the same original energy level. Other times part of the photon's energy is used to heat the atom

<sup>164</sup> Ibid., 62.

<sup>165</sup> See this study's Appendix for a fuller treatment of emission and absorption spectra.

or increase its vibration and a lower-energy photon is re-emitted. Thus the wavelength is increased and the photon is reddened. If a great deal of absorption and scattering takes place, especially by interstellar dust, the radiation is all converted into heat energy. The result is the dimming of light and the extinction of starlight.

We have much better clues and knowledge of interstellar space and mediums than had Hubble and others in his day. For instance, interstellar space contains mainly hydrogen and plasmas, but also many heavy (heavier than helium) elements have been found in recent years. Interstellar dust appears to be made of carbon or magnesium and iron silicates, and interstellar space that is closer to stars or quasars is more dense, hotter, and turbulent. Furthermore, the temperature of the interstellar medium varies enormously, which may affect travelling photons.

In addition, scientists have identified about 91 distinct molecular species along with some 30 variations containing different isotopes of carbon, oxygen, and hydrogen. Yet there remains about 150 interstellar bands and molecules unidentified. Also, it appears the universe contains a uniform amount of cosmic microwave background radiation with unknown interactions, plus x-rays, gamma rays, cosmic rays, and radio waves.

The question arises in light of the above knowledge that when it's very probable that photons do lose energy and increase wavelengths in outer space, why haven't interstellar collisions been credited with causing the redshift as opposed to expansion?

The main reason is the assumption that redshifting caused by such scattering would produce diffuse and nebulous spectral lines. Since sharp spectral lines are seen on spectra, it is concluded that interstellar reddening is not significantly occurring - if at all. However, spectral images from the alleged farthest reaches of space are actually

somewhat diffuse, which would indicate an interstellar-medium effect. Furthermore, as is the case with the Compton effect, it's also possible that over vast distances light could increase in wavelength, lose energy, and still not be scattered so far off its course as to blur lines significantly. So, the blurring objection may not be as conclusive as thought.

Although there is a greater understanding of interstellar space since the 1930s, one of the most important realizations is that scientists now know enough to surmise that a great deal is unknown concerning what actually is occurring due to the travel of light through the interstellar mediums. For instance, outer space is by no means uniform in composition, motion, density, temperature, gravity, etc. Furthermore, new research is continually coming in regarding photon-photon interactions as well as the nature of light and optical phenomena. No one can be positive that light traveling over billions or trillions of miles is not reddened by one or more means, including the interstellar medium.

### The Light-Coherence Theory

"Cosmologists are often wrong, but never in doubt," began a 1991 article about the latest serious challenge to the optical Doppler theory of redshifts:<sup>166</sup>

After decades of intense research, they [cosmologists] still cannot say much about the size and shape of the universe. But they are sure of one thing: it expands. The farther away a galaxy is, the more its light is shifted towards the longer, redder wavelengths of the spectrum. This is taken to be a "Doppler shift"....The red shift is thus evidence - by far the best evidence - for the idea of an expanding universe. However, even fundamental tenets of faith can be questioned. In 1986 a physicist [Emil Wolf] at the University of Rochester, New York, claimed that it was possible to generate a red shift in light without moving the source.

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<sup>166</sup> The Economist, "Cosmological Doubt Receding," The Economist (14 December 1991): 92-3.

His idea was that light scattering off material moving at random in a galaxy could end up redder than it was when it started. So a galaxy could get a red shift quite independent of its movement.<sup>167</sup>

The reason Wolf wasn't summarily brushed off, the article surmised, was because he is an internationally respected optics expert, who authored a classic text on optics with the famous Max Born.

The following year after Wolf published his findings, the underlying physics behind his theory was verified in laboratory experiments. Dr. Wolf and his associate Dr. Daniel James believe the right conditions for causing redshifts may exist in quasars.

Wolf's experiments and hypotheses reveal the possibility that the redshift-distance relation and Hubble law could be incorrect even though seeming to work within tremendous error factors and despite the seeming "proof" that spectral readings are accurately representing characteristics of emitting sources. One systematic error could be the "assumption of invariance of the spectrum on propagation," regardless of the exceeding distances or intervening media. In other words, the assumption that light is not affected through space travel may be suspect. In fact, Wolf goes so far as to say this assumption is wrong: "This fact is undoubtedly largely responsible for the commonly held, but nevertheless incorrect, belief that spectral invariance is a general property of light."<sup>168</sup>

What is light coherence and how does it occur in space? Wolf talks about light that is either coherent or incoherent. In incoherent light, photons are emitted with many different frequencies and phases of vibration in various directions. As it spreads

<sup>167</sup> Ibid., 92.

<sup>168</sup> Emil Wolf, "Invariance of the Spectrum of Light on Propagation," Physical Review Letters 56, no. 13 (31 March 1986): 1372.

out wider with distance, it decreases in intensity, much like the beam from a flashlight becomes diffuse. The light waves are out of phase with one another at different frequencies and heading in all sorts of direction. In coherent light, on the other hand, the photons have exactly the same frequency, phase, and direction. Therefore, coherent light does not become diffuse with distance, relatively speaking. An example of coherent light is a laser.

Ordinary photon scattering, whether within a star, in its corona or outer atmosphere, or passing through a gas cloud, proceeds at random in any direction of all the spherical possibilities. Thus, this type of light becomes more diffuse as it travels. But, according to Wolf and fellow optical physicists, when conditions cause scattering to proceed in a given rather than random direction, this is due to "source coherence" of various types: "in this case the redshift increases quadratically with the spectral source-correlation length."<sup>169</sup>

What kind of physical mechanism could produce source correlations? Wolf mentions different combinations of refractive indexes and incident waves, medium characteristics, and some cooperative phenomena such as superradiance and superfluorescence.

In a 1990 article, Daniel James, Malcom Savedoff, and Emil Wolf clearly indicate that light from galaxies as well as from quasars could be redshifted by particular conditions which create coherence and result in Doppler-like sharp spectral lines.<sup>170</sup>

<sup>169</sup> Emil Wolf, "Non-cosmological Redshifts of Spectral Lines," *Nature* 326 (26 March 1987): 364.

<sup>170</sup> Daniel F. V. James, Malcolm P. Savedoff, and Emil Wolf, "Shifts of Spectral Lines Caused by Scattering from Fluctuating Random Media," *Astrophysical Journal* 359 (10 August 1990): 67-71.

One of their visual illustrations shows that whether an observer sees a redshift or a blueshift depends on his or her location with respect to the light-emitting source. Since Earth always views starlight from a line-of-sight perspective, it generally sees outer-space objects as reddened. If this is the case, then the expansion of the universe based on redshift data would be seriously undermined..

Another consequence of the Wolf effect is the possible undermining of the Big Bang Theory. For instance, a 1992 article makes the startling conclusion that the Wolf effect "explains the redshifts of galaxies without resorting to cosmic expansion, thus getting rid of the need for the Big Bang."<sup>171</sup>

The Wolf effect is also supplemented by recent astronomical studies from the Lockheed Martin Palo Alto Research Laboratories in conjunction with Utrecht University and the Dutch Space Research Organization. A 1995 article reporting on this joint study explains that "before reaching astronomers' telescopes, a star's light also has to travel through its corona. Previously, astronomers thought that this wispy atmosphere let light through unimpeded. But Karel Schrijver and his colleagues...now say that coronas scatter light."<sup>172</sup> This raises the question as to whether light is redshifted before it ever leaves the star.

### The Transverse-Velocity Redshift Theory

According to Hubble's redshift-velocity interpretation, Doppler effects can be detected on the line-of-sight between the observer and the receding or approaching object. But what about objects that are going sideways (i.e., perpendicular) to the

<sup>171</sup> Anthony L. Peratt, "Plasma Cosmology," Sky and Telescope (February 1992): 140.

<sup>172</sup> Alison Goddard, "Starlight Vanishes in Celestial Fog," New Scientist (June 1995): 24.

observer or orbiting at some angle between a radial line-of-sight and a perpendicular motion? Might they produce a redshift due to their transverse velocities?

Most sources typically explain a transverse-velocity effect as relativistic. But could there be a non-relativistic transverse velocity effect due to large-scale "sideways" motions of galaxies, superclusters, etc.?

P. Burcev worked out calculations for an optical non-relativistic transverse velocity effect for rotating galaxies. He concluded "we see that the observed red-shift does not necessarily imply that objects recede away from us and that the universe expands!"<sup>173</sup>

In spite of Burcev's calculations, cosmologists have favored an expansion cause for redshifts, thereby ruling out rotation of large-structures of the universe. However, in recent years it has been discovered that galaxies, galaxy clusters, and even superclusters have sideways "streaming" motions on a large scale, not just local peculiar motions.

The discoveries of large-scale streaming flow began in 1987. Further studies confirmed findings in 1990. Alan Dressler and S.M. Faber reported that "the new data confirm the results of these earlier studies of a coherent flow pattern in a large region called the 'great attractor.'"<sup>174</sup>

In 1994, Tod Lauer of the National Optical Astronomy Observatories and Marc Postman of the Space Telescope Science Institute reported far more vast lateral motion that had ever been dreamed. Fay Flam commented:

<sup>173</sup> P. Burcev, "Receding or Circulating Quasars?" Physics Letters 27A, no. 9, (23 September 1968): 623-24.

<sup>174</sup> Dressler, A., and S. M. Faber, 1990, Astrophysical Journal, L45.

That observation [indicating a Great Attractor], which takes in a region of the universe about half a billion light-years wide, has disoriented astronomers who were hoping for still waters....At face value, it implies the existence of a universe that is uneven on scales far larger than theorists can explain with current models of structure formation, says Princeton theorist Bohdan Paczynski. And if not that, he says, maybe there's something wrong with cosmologists' very definition of what is at rest and what is moving.<sup>175</sup>

In other words, the Great Attractor phenomenon creates problems either for the formation of structures in the universe or for whether there is a comoving coordinate system where galaxies or superclusters are at rest relative to their space.

Still not willing to concede large-scale rotation, astronomers continued searching for some other explanation for this great attraction of galaxies. When instruments detected a slight temperature gradient in the microwave background radiation from one side of the sky to the other, cosmologists assumed the cause was our Galaxy's own peculiar motion over and above the expansion of the universe. Correcting for our motion, they thought, would yield a true rest frame. But they were disappointed:

Based on that assumption, astronomers made the peculiar-velocity measurements that culminated in the discovery of a vast stream of thousands of galaxies all headed for a spot in the sky dubbed the "great attractor."<sup>176</sup>

Lauer and Postman had hoped to take measurements and do corrections to find the clusters' deviation from the smooth expansion of the universe and to find the boundaries of the lateral movement. Instead, they found motions on a scale roughly one-tenth the size of the observable universe.<sup>177</sup> This left astronomers trying to figure

<sup>175</sup> Flam, F., 1993, Science, 31.

<sup>176</sup> Ibid.

<sup>177</sup> Evrard, A. E. and N. Kaiser, Nature, 806.

out what these thousands of galaxies are heading towards. Though sceptical, colleagues have been unable to find holes in the robustness of Lauer's and Postman's data; all are waiting for "further studies."

In the meanwhile, the very old but generally discredited idea that the universe might be on some large scale rotating might not be an entirely unreasonable possibility. In fact, in 1982 Birch wrote an article suggesting redshifts could be at least partly due to transverse motion if the universe had an overall momentum. He concluded, "Thus there appears to be strong evidence that the Universe is anisotropic on a large-scale, producing position angle offsets in the polarization and brightness distributions of radio sources. These can probably be explained by a rotation of the Universe...."<sup>178</sup>

### The Gravitational Redshift Theory

Gravitational redshifting is explained in the following way. According to relativity theory, the greater the mass of an object, the more it indents space-time and changes its local curvature. Thus a star, which has a large mass, makes a significant indentation in space-time. When this star emits photons, the photons must "climb out" of the gravitational indentation of the star. In so doing, the photons lose energy and are thereby reddened. Although cosmologists make corrections in their calculations using spectral redshifts, gravitational redshifting is believed to be very small.

### Conclusion

In this chapter the only three reasons apparently cited as evidence for assuming expansion rather than nonexpansion of the universe were stated: (1) the redshift-distance relation, (2) the Hubble law, and (3) the space-expansion redshift theory.

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<sup>178</sup> P. Birch, "Is the Universe Rotating?" Nature 298 (29 July 1982): 453.

Next, the redshift-distance relation and the Hubble law were examined to see whether they presently provide good and compelling reasons for assuming expansion rather than nonexpansion of the universe. Due to the extraordinary difficulty in calculating distances, which both the redshift-distance relation and the Hubble law fundamentally depend on, it was concluded that their validity and reliability were not as well-confirmed as is often claimed since there existed a distance-measurement margin of error of a factor of two. However, it should be noted that this problem does not disconfirm the redshift-distance relation or the Hubble law. Rather, it raises doubt on how well confirmed they are, which lessens their strength as well as that of any argument relying on them to conclude the universe is expanding.

In addition to the distance problems, various difficulties specifically relevant to the Hubble law were considered. Although there is strong evidence that Hubble was incorrect in concluding there existed a redshift-distance relation and thus a Hubble law, this is irrelevant to whether there presently is evidence for a Hubble law. Results from a recent infrared-astronomical-satellite (IRAS) study render the Hubble law invalid. Furthermore, another investigation revealed that sampling used to confirm the Hubble law is biased, unrepresentative, and contains systematic errors as well as the deletion of discrepant data.

Based on the above analysis, this chapter concludes that presently the Hubble law cannot be considered a good and compelling reason to assume expansion rather than nonexpansion of the universe. On the other hand, although the redshift-distance relation faces distance-measurement difficulties, it has not been disconfirmed and even has some confirmational basis within its margin of error - especially for relatively nearby distances. Therefore, the redshift-distance relation still can be considered as a good and compelling reason to conclude expansion rather than nonexpansion of the

universe. However, in order to make such a conclusion, there needs to be a good and compelling reason to assume space-expansion redshift theory rather than any of the other redshift theories presented. Therefore, this study's final task in the next chapter is to determine whether this is the case as most cosmologists seem to claim.

## CHAPTER V

### THEORETICAL VIRTUES

This chapter will examine whether there are any good and compelling reasons to assume space-expansion redshift theory rather than some alternative redshift theory. If there are such reasons, then space-expansion redshift theory would itself be a good and compelling reason for cosmologists starting anew to assume expansion cosmology. Therefore, space-expansion redshift theory and the other redshift theories will be examined to see what - if any - good and compelling reasons each possess. But first, it is helpful to define what constitutes a "good and compelling reason" with reference to a theory.

#### Definition of "A Good and Compelling Reason"

For the purposes of this study, roughly a theory possesses a good and compelling reason for assuming it rather than another theory when it possesses a virtue(s) that provides more convincing justification for it being more likely true than any of the other competing theories. Thus, this study is interested in virtues that are truth-conducive.

Although several truth-conducive virtues are discussed in philosophy of science, this study will focus on the following four virtues of scientific theories: (1) explanatory power, (2) predictive power, (3) testability, and (4) consistency. The first two are sometimes called external virtues since they refer to a theory's relation to the world and, therefore, depend on observation in order to be evaluated. The last two are sometimes called internal virtues because they refer to a theory's relation to itself

and its conceptual relation to other theories. Thus, they don't depend on observation in order to be evaluated.<sup>181</sup>

## Explanatory Power

### Definition

Explanatory power refers to a theory's ability to explain or account for some observable phenomenon. In the present case, the following redshift theories need to account for both redshifts and the redshift-distance relation.

### The Intrinsic-Property Redshift Theory

The intrinsic-property redshift theory was proposed to explain quantization, quasar, and discordant redshift phenomena. It posited that such redshifting might be the result of qualitative and quantitative intrinsic features of stars, quasars, galaxies, and other light-emitting celestial phenomena. Not only can it account for redshifts, but it can account for the redshift-distance relation. For instance, as discussed in the previous chapter, one way intrinsic redshifts can account for a redshift-distance relation is if both stars and galaxies possess intrinsic properties that produce certain redshift wavelengths based on their morphology. If galaxies roughly fall at unique distances based on their morphology, the result might be a redshift-distance relation.

There is another way intrinsic-property redshift theory can account for redshifts and the redshift-distance relation. If intrinsic properties of stars and galaxies roughly produce equal amounts of redshifting that gradually decreases over time, then

<sup>181</sup> For a concise discussion of several notable theoretical virtues, see Peter Kosso, Reading the Book of Nature: An Introduction to the Philosophy of Science (Cambridge University Press, 1992): 27-50.

the light received from distant objects would have a larger redshift than light from a nearby object due to the greater time it takes light to travel from the far object. The result would be a redshift-distance relation. Therefore, the intrinsic-property redshift theory could account for the observable data.

### The Compton Redshift Theory

The Compton redshift theory is based on photons losing energy and thus reddening after colliding with electrons that lost some of their energy in photon collisions. Since space is estimated to be comprised of a plasma consisting of approximately one electron and one proton per 100 cubic centimeters, light travelling through space will be reddened in proportion to the distance transversed. Thus, the Compton redshift theory can account for the observable data.

### The Interstellar-Medium Redshift Theory

The interstellar-medium redshift theory is based on photons losing energy and thereby reddening due to encountering an interstellar medium. For instance, a photon may be absorbed and re-emitting at a longer wavelength due to colliding with interstellar dust. Since the greater the distance light must travel, the more likely it is to encounter more interstellar media and redden. The result would be a redshift-distance relation. Therefore, this redshift theory can also account for both redshifts and the redshift-distance relation.

### The Light-Coherence Redshift Theory

The light-coherence redshift theory was proposed by the internationally-renown optics expert Emil Wolf in order to explain discordant redshifts such as

quasars. When conditions are right, starlight is brought into coherence, which means that its waves possess the same frequency and wavelength as well as are in phase with one another like a laser beam. Not only can this redshift theory explain discordant redshift phenomena, but some cosmologists claim that it can explain galactic redshifts without "resorting to cosmic expansion." Therefore, the light-coherence redshift theory can account for the observable redshift and redshift-distance-relation phenomena.

### The Transverse-Velocity Redshift Theory

The transverse-velocity redshift theory is somewhat in the same family as the optical-Doppler redshift theory. The transverse-velocity redshift theory proffers that light might be redshifted as a result of light-emitting sources moving laterally or sideways to a light receiver. One way that this theory can account for the redshift-distance relation is if the universe rotated on a macro-level with the Milky Way Galaxy near its center. Thus, the farther away a star or galaxy is from the Milky Way Galaxy, the greater its velocity and, consequently, a redshift-distance relation would result.

As reported in the previous chapter, cosmologists Tifft, Guthrie, and Napier have found redshift quantization from the center of the Milky Way Galaxy, which is consistent with the Milky Way being some center point of the universe and the universe rotating on a macro-level. Furthermore streaming, which was also discussed, seems to indicate motion on a large scale. Therefore, the transverse-velocity redshift theory can account for redshifts and a redshift-velocity relation.

### The Gravitational Redshift Theory

The gravitational redshift theory proposes that large mass objects such as stars indent space-time. Consequently, emitted photons lose energy and become reddened while trying to "climb out" of this gravitational indentation. Since cosmologists claim that redshifting due to gravitational effects is very small, the gravitational redshift theory is not able to account for total redshifting or a redshift-distance relation by itself. But it could contribute to redshift phenomena in a limited degree.

### The Optical-Doppler Redshift Theory

The optical-Doppler redshift theory states that recessional motion between a light-emitting source and a corresponding light receiver produces a redshift proportional to the intervening distance. If galaxies possess recessional motion, then the optical-Doppler redshift theory can account for both redshifts and a redshift-distance relation.

### The Space-Expansion Redshift Theory

The space-expansion redshift theory proposes that expanding space stretches photons, which results in the lengthening and redshifting of these photons. The more expanding space a photon must travel through, the more it is stretched. Therefore, the space-expansion redshift theory can account for both redshifting and a redshift-distance relation.

### Conclusion

Except for the gravitational redshift theory, all the redshift theories can explain both redshift data and a redshift-distance relation. Furthermore, all eight redshift

theories can account for both redshift data and a redshift-distance relation by combining two or more of these theories. Therefore, all eight redshift theories possess the virtue of explanatory power, but the gravitational redshift theory to a much lesser degree.

### Predictive Power

#### Definition

Predictive power involves testing to determine if a theory's prediction(s) is correct. If the theory's prediction passes the test, then this is confirmational evidence for the truth of the theory and the theory is said to have predictive power.

#### The Intrinsic-Property Redshift Theory

Intrinsic-property-redshift-theory predictions have not been confirmed as yet. On the other hand, it has not been disconfirmed either. Therefore, its predictive power is presently indeterminate.

#### The Compton Redshift Theory

Compton-redshift-theory predictions have been thoroughly confirmed in laboratory experiments for decades. Therefore, it has predictive power.

#### The Interstellar-Medium Redshift Theory

Interstellar-medium-redshift-theory predictions have been confirmed in laboratory experiments. Therefore, it has predictive power. In addition, in recent decades radio, ultraviolet and high-energy telescopes, particle counters and magnetic

field probes have shown that space is teeming with electrically charged subatomic particles.

### The Light-Coherence Redshift Theory

The underlying physics predicted by the light-coherence redshift theory has been confirmed in laboratory experiments. Therefore, it has predictive power.

### The Transverse-Velocity Redshift Theory

In vivo experiments, whose results have been applied to medical procedures, it has been confirmed that transverse-velocity predicted effects can supply information about liquid flow streaming past the detector, even at 90 degree angles of perpendicularity provided that good-quality pulsed Doppler electronics and fast fourier transform are used. Although these experiments do not involve light and redshifting, they indirectly provide some reason to think the transverse-velocity redshift theory might have some more relevant empirical merit in the future. But as of yet, its predictions have not been confirmed nor disconfirmed.

### Gravitational Redshift Theory

Currently, experiments related to the gravitational redshift theory are inconclusive. Therefore, although this redshift theory doesn't have much confirmational support, neither has it been disconfirmed.

### The Optical-Doppler Redshift Theory

The optical-Doppler-redshift-theory predictions concerning our sun's shifted spectral lines was confirmed by H.C. Vogel in the 1870s and has been further verified via other experiments. Therefore, it has predictive power.

### The Space-Expansion Redshift Theory

Space-expansion-redshift-theory predictions have been neither confirmed nor disconfirmed at the present time. Part of the difficulty is that scientists can't create expanding space to be tested for its effects on light. Neither are they able to go where space is claimed to be expanding in the universe.

### Conclusion

Based on the above discussion, it is concluded that none of the above eight redshift theories' predictions have been presently disconfirmed. Furthermore, only two redshift theories currently lack any confirmation: (1) the intrinsic-property redshift theory, and (2) the space-expansion redshift theory.

### Testability

#### Definition

Testability is the capacity of a theory to make predictions that can be tested and that are not predetermined to be correct. Thus, testability is different from predictive power, which involves the actual passing of a test.

## Conclusion

As is evident from the previous section concerning predictive power, all eight theories possess the virtue of testability, even though the actual testing has not been practically possible for some of these theories at the present time.

### Consistency

#### Definition

Usually, consistency refers to whether a theory is consistent or compatible with other well-established beliefs or well-confirmed theories. However, since this study is concerned with whether there are any good and compelling reasons for cosmologists starting anew to assume that any new cosmological theory would have to assume expansion rather than nonexpansion of the universe, the relevant issue is whether the following eight redshift theories are consistent with expansion and nonexpansion theory.

#### The Space-Expansion Redshift Theory

All of the redshift theories - except the space-expansion redshift theory - are consistent with both expansion and nonexpansion cosmology. Although space-expansion redshift theory is consistent with expansion cosmological theory, it is inconsistent with nonexpansion cosmological theory. This inconsistency is due to the fact that this redshift theory entails expanding space and, therefore, an expanding universe. This entailment results in a logical contradiction when incorporated into nonexpansion cosmological theory.

## Conclusion

There are at least two ways to view the space-expansion-redshift-theory's inconsistency or incompatibility with nonexpansion cosmological theory. First, it might be argued that since the space-expansion redshift theory is inconsistent with nonexpansion cosmological theory, it therefore lacks the virtue of consistency. Since the other redshift theories possess the virtue of consistency, it can be concluded that in this respect the space-expansion redshift theory has no good and compelling reason for its assumption.

Second, the inconsistency problem can be viewed from the perspective of the two main cosmological theories in a way that favors space-expansion redshift theory. For instance, it might be argued that since expansion cosmological theory is consistent with all eight redshift theories but nonexpansion cosmological theory is inconsistent with space-expansion redshift theory, this is a good and compelling reason to assume expansion cosmological theory and, therefore, space-expansion redshift theory rather than some alternative redshift theory. This reasoning, however, leads to circularity.

## Circularity

The circularity problem between expansion theory and space-expansion redshift theory can be seen in the following way. In the above reasoning, expansion cosmological theory is used to argue that space-expansion redshift theory should be assumed rather than some other redshift theory. But, in order to argue that cosmologists starting anew should assume expansion of the universe, space-expansion redshift theory is then applied to the redshift-distance relation and it is argued that this is strong evidence for assuming expansion rather than non-expansion of the universe. Thus, cosmological expansion theory is used to argue for space-expansion redshift

theory and space-expansion redshift theory in turn is used to argue for cosmological expansion theory.

## Conclusion

The question originally asked at the beginning of this chapter was whether there presently are any good and compelling reasons to assume space-expansion redshift theory rather than some alternative redshift theory. It was determined that the space-expansion redshift theory possessed the virtues of explanatory power and testability. Furthermore, although its predictions have not yet been confirmed, neither have they been disconfirmed, so its possessing the virtue of predictive power is presently indeterminate. In addition, although the space-expansion redshift theory was found to be consistent with expansion theory, this consistency entailed circularity.

Most of the remaining seven alternative redshift theories fared much better quantitatively than the space-expansion redshift theory in that they possessed three or even all four of the virtues. Although it is debatable whether the criteria for assuming one theory rather than another should depend largely on quantitative grounds, it is reasonable to at least conclude that there presently are no good and compelling reasons to assume space-expansion redshift theory rather than some alternative redshift theory. Furthermore, the space-expansion redshift theory doesn't seem to possess any qualitative edge over the other redshift theories that would provide a good and compelling reason to assume it. Consequently, space-expansion redshift theory is not presently a good and compelling reason for cosmologists starting anew to assume that any new cosmological theory would have to assume expansion rather than nonexpansion of the universe.

## CHAPTER VI

### CONCLUSION

#### Summary

In the first chapter of this study, it was stated that there existed a current crisis in contemporary cosmology. It was stated that there are two ways to resolve this crisis. Either cosmologists can continue working on big bang theory, as they have been doing for some time, or start anew. This study's thesis was that if some cosmologists start anew, it would be a mistake for them to assume that any new cosmological theory would have to explain expansion rather than nonexpansion of the universe.

Chapter II provided reasons for stating there was a current crisis in contemporary cosmology because it might be objected that if there is no crisis, then cosmologists would not consider starting anew and, consequently, this study's thesis would be a moot point. Therefore, several examples supporting a crisis evaluation were discussed. Furthermore, it was argued that some cosmologists at least perceived a current cosmological crisis, which could be reason enough for them to start anew.

Chapter III examined whether there were any good and compelling reasons for changing from static to expansion cosmological theory in the early 1930s. Based on a historical survey of relevant developments covering over a century, it was concluded that there were good and compelling reasons by the early 1930s to make this change.

Chapter IV noted three reasons commonly cited as strong evidence for the expansion of the universe: (1) a redshift-distance relation, (2) the Hubble law, and (3)

the space-expansion redshift theory. It was concluded that the Hubble law appeared to be presently invalidated and the redshift-distance relation was less confirmed than some cosmologists may have thought.

Chapter V examined whether there were any good and compelling reasons for assuming space-expansion redshift theory rather than some other redshift theory. Eight redshift theories, including the space-expansion redshift theory, were evaluated in light of four virtues of scientific theories: (1) explanatory power, (2) predictive power, (3) testability, and (4) consistency. It was concluded that the space-expansion redshift theory possessed the first two virtues, its predictions were neither confirmed nor disconfirmed, and although it was consistent with expansion theory but inconsistent with nonexpansion theory, it suffered from circularity with reference to expansion cosmological theory. Since the other redshift theories fared at least somewhat better, it was concluded that there were no good and compelling reasons for assuming space-expansion redshift theory rather than nonexpansion theory.

### Conclusion

Based on the above analysis and conclusions, this study's thesis has been supported that if some cosmologists start anew, it would be a mistake for them to assume that any new cosmological theory would have to explain expansion rather than nonexpansion of the universe.

## Appendix A

### Background Cosmological Concepts

This Appendix provides a review of five scientific concepts, which are foundational to this study: (1) electromagnetic radiation, (2) the Doppler effect, (3) photon emission, (4) spectroscopy, and (5) spectral redshifts. If these concepts are already familiar, the reader may omit this section and proceed directly to chapter three.

### Electromagnetic Radiation

Electromagnetic radiation is carried in the form of waves of interacting electric and magnetic fields. These waves can be pictured in a very simplified way. Imagine that one end of a rope is nailed to a wall and the other end is held in a person's hand. If the person rhythmically moves her hand up and down at a constant rapid pace, the rope will exhibit a uniform wave pattern similar to a connected series of the letter "S" lying down at a ninety degree angle, such as "~"; this special type of curve is called a sine curve.

The high points of a wave are called crests and the low points are referred to as troughs. A wavelength is the distance from one crest to the next one, and the frequency of a wave is the number of crests that pass a specified point given a certain period of time. For example, if three crests pass a certain point each second, then the wave frequency is three and the wave speed is three wavelengths per second. (More accurately, frequency refers to the number of vibrations in a certain period of time. In the rope example above, the person's hand is exhibiting a vibrating motion. Every up and down movement equals one vibration. If her hand makes three complete vibrations each second, then its frequency is three. The reason why the wave seen via the rope also is said to have a frequency of three is because each crest is the result of her hand's upward motion and each trough corresponds to its downward movement. Thus, the rope-wave is an extension of her vibrating hand).

Physicists have determined a certain relationship between a wave's velocity, frequency, and length, which is expressed by the following equation:  $\text{velocity} = \text{frequency} \times \text{wavelength}$ . This relationship means that given any velocity, it is possible for an electromagnetic wave to have an infinite number of frequencies and wavelengths. This is extremely important when considering redshifts, especially since it is believed that all electromagnetic waves, including visible light, move at a constant speed of approximately 300,000 kilometers per second in a vacuum. Thus, assuming visible light waves relatively maintain this constant speed as they travel throughout interstellar space, it is possible for light emitted from a star at a certain frequency and wavelength to reach an observer on earth at its initial velocity but with a lower frequency and a correspondingly longer wavelength. Such a change to a longer wavelength is commonly called a "redshift."

The different categories of electromagnetic radiation can be diagrammed on a continuum, with the longest wavelengths on the far left and the shortest ones on the far right. Although the various types of electromagnetic waves found on this electromagnetic spectrum possess no sharp dividing lines between each other and actually overlap, they are roughly categorized by frequency and wavelength in the following order, from lowest frequency and longest wavelength to highest frequency and shortest wavelength: (a) radio waves, (b) microwaves, (c) infrared waves, (d) visible light waves, (e) ultraviolet rays, (f) x-rays, and (g) gamma rays.

Our unaided eyes can only perceive visible light, which makes up less than a millionth of one percent of the electromagnetic spectrum. Within this range of wavelengths, which our retinas recognize as colors, visible light waves extend from the longest in length to the shortest in the following sequence: (a) red, (b) orange, (c) yellow, (d) green, (e) blue, and (f) violet. Thus, an elongation of any visible

wavelength is toward the direction of the color red; hence, the name "redshift." And the shortening of any visible wavelength is toward the direction of the color blue; hence, the name "blueshift."

In addition to its wave nature, electromagnetic radiation possesses a particle aspect. Electromagnetic radiation travels in tiny energy-filled particle packets called photons. Electromagnetic radiation with more energy per photon has higher frequencies and shorter wavelengths (such as ultraviolet, x-rays, and gamma rays), while that with less energy has correspondingly lower frequencies and longer wavelengths (such as infrared, microwaves, and radio waves). Although in common conversation the term "photon" is connected with visible light, it actually refers to any kind of electromagnetic radiation, since all electromagnetic radiation travels in the form of photons.

### The Doppler Effect

Different types of waves travel in different ways. There are two fundamental kinds of waves: sound and electromagnetic radiation.

Sound waves need atoms and molecules in order to travel; they cannot transmigrate in a vacuum, which is only empty space. When the atoms of an object vibrate, such as the atoms comprising a guitar string, the guitar-string atoms collide with the atoms of adjacent air molecules, which results in the air molecules also vibrating. In chain-reaction manner, these vibrating air molecules collide with other adjacent air molecules, which also begin to vibrate. If eventually air molecules next to an auditory being's ear also begin to vibrate, then atoms in the ear will begin vibrating. The normal result is the perception of sound.

Electromagnetic radiation waves, on the other hand, can travel either in a vacuum or by various collisions with other atoms and molecules. Once the photon particle is set vibrating in motion, it will continue to move in the same direction in which it was emitted until it encounters some other atom, where, depending on the kind of atom encountered, it is sometimes absorbed and then re-emitted. Sometimes the photon is re-emitted in the same direction, but usually it is scattered in various other directions.

Sound and electromagnetic radiation waves produce a certain effect when either the wave-emitting source or the wave receiver are moving toward or away from each other. This effect is called either the sound or optical Doppler, depending on the kind of wave involved.

The sound (or acoustical) Doppler effect applies to sound waves and can be explained by the following example. Suppose a sound source, say a stationary car with its horn stuck, continually sends out sound waves equally in all directions; thus, it emits sound waves at a constant frequency and wavelength. If a person is standing still some distance in front of the car, she will receive the sound waves at a constant frequency and wavelength just as emitted by the car horn. If either or both the person or the car begin moving toward each other, then the person will receive the sound waves at a higher frequency and shorter wavelength even though the car is still emitting the sound waves at the original constant frequency and wavelength. This occurs because of the following reason: since the distance the sound wave must travel between the person and the car has decreased, the person receives the horn's constantly emitted frequency more often, which creates the effect to the person that the emitted horn sound itself has increased in frequency and also shortened in wavelength, even though it hasn't. Conversely, if either or both the person or the car

begin moving away from each other, then the person will receive the sound waves at a lower frequency and longer wavelength even though the car is emitting the sound waves at the original constant frequency and wavelength.

The optical Doppler effect commonly refers to visible light waves, although it can be applied to all electromagnetic radiation waves.. It is analogous to the sound doppler. Suppose that a light source, say a star, continually sends out light waves equally in all directions; thus, it emits light waves at a constant frequency and wavelength. If an observer is stationed on earth, then he will receive the light waves at a constant frequency and wavelength just as emitted by the star, provided neither the star nor earth are moving in relation to one another. If either or both the star or the observer begin moving toward each other, then the observer will receive the light waves at a higher frequency and shorter wavelength even though the star is emitting the light waves at the original constant frequency and wavelength. This occurs for the following reason: since the distance the light waves must travel between the observer and the star has decreased, the observer receives the star's constantly emitted frequency more often, which creates the effect to the observer that the emitted starlight itself has increased in frequency and also shortened in wavelength, even though it hasn't. Whenever visible light increases its frequency and shortens its wavelength, it moves to the right on the electromagnetic spectrum toward blue light; such a change of position is called a "blueshift." Conversely, if either or both the observer or the star begin moving away from each other, then the observer will receive the light waves at a lower frequency and longer wavelength even though the star is emitting the light waves at the original constant frequency and wavelength. Whenever visible light increases its frequency and shortens its wavelength, it moves to the left on the electromagnetic spectrum toward red light; such a change is called a "redshift."

## Photon Emission

Visible light is the result of atoms emitting photons. This process of photon emission depends on the structure of the particular type of atom. An atom consists of a nucleus containing positively charged protons and uncharged neutrons. The nucleus is surrounded by negatively charged electrons. The electrons are located in the atom's "shells," which are located at permitted energy levels. The permitted energy levels for each atom depend on the number of protons in its nucleus. Each kind of atom (in chemistry they are called elements) has its own number of protons. Normally, the number of electrons in an atom equals the number of protons. The electrons first "fill up" the closest shell to the nucleus and then increasingly farther ones. The level with highest-binding energy closest to the nucleus and the one with the lowest-binding energy is farthest away. This means, therefore, that the lower the binding energy, the less energy is needed to pull electrons away.

When an electron receives an increase in energy, such as from a collision with a photon, the electron is said to be "excited" and quickly jumps to a higher-energy shell. Usually after only a fraction of a second, the excited electron returns to a lower-energy shell, thereby releasing a photon with a wavelength corresponding to the amount of energy the electron has just given up.

Each kind of element emits only certain wavelengths of photons based on its own shell distances that are determined by the number of protons. The collection of the various wavelengths emitted by each kind of element forms an unique identifying "fingerprint." Scientists, via laboratory experiments, have identified the various fingerprint patterns of the known elements.

## Spectroscopy

A knowledge of each element's fingerprint pattern is especially useful to astronomers in determining the gaseous composition of a star's atmosphere. For instance, first consider the hypothetical case where no gaseous atmosphere exists around a star. Suppose this hypothetical star emits photons of every wavelength in the visible light range. These various wavelengths would sort of blend together to produce the appearance of white light. When the blended light from this star reaches earth, astronomers could use an instrument called a spectroscope to separate the blended light waves back into their original wavelengths, each of which also has its own unique subtle shade of color. The separated result would resemble a film strip with a continuous spectrum of the following colors, which blend one into another with no sharp discrete borders: (a) red, (b) orange, (c) yellow, (d) green, (e) blue, and (f) violet. This type of spectrum is called a "continuous spectrum."

If starlight didn't pass through any layers of gas atoms on its way to earth as in the hypothetical case above, there would be no unique fingerprints for astronomers to identify because the starlight would produce a continuous spectrum. Fortunately, starlight does pass through layers of gas in its atmosphere. The gas absorbs photons of certain wavelengths that correspond to the unique distances between the shells within an atom of the gas. These photons are temporarily absorbed by the gas while the remaining light passes by untouched. The energy from the captured photons excites the gaseous atoms' electrons into higher energy states for a split second. Then the electrons return to a lower energy state and re-emit photons of wavelengths corresponding to the unique shell distances of the gas's atoms.

But the gas atoms usually don't re-emit the photons in the same direction as they had initially been traveling. Rather, they send the photons in random directions,

where they may similarly interact with other atoms of the gas many times and be scattered yet in new directions each time.

It is this absorption and scattering process that is helpful to astronomers. For instance, when the remaining uncaptured starlight reaches earth and an astronomer's spectroscope, it is missing the wavelengths that were absorbed and scattered by the star's gaseous atmosphere. In place of the missing wavelengths on the otherwise continuous spectrum are relatively thin dark lines. These dark lines indicate the fingerprint(s) of the gaseous element(s) in the star's atmosphere. This type of readout is called an "absorption spectrum" because it reveals which wavelengths were absorbed before reaching the spectroscope.

On the other hand, if astronomers focus their spectrosopes on the part of the atmospheric gas cloud to the side of the star, they will receive light only from the photons that were scattered by the gas. This spectroscopic readout, called an "emission spectrum," would resemble a sort of film negative of the absorption spectrum; that is, it would be black where the absorption spectrum was colored and colored where the absorption spectrum was black. In essence, the emission spectrum is mostly black with thin colored lines. On both the absorption and emission spectra, the relatively thin lines (whether colored or dark) are referred to as "spectral lines." Once again, since astronomers know the fingerprints of each element's gas, they can compare the fingerprints indicated by the spectral lines of the light received from stars and gas in outer space in order to determine a star's atmospheric composition.

### Spectral Redshifts

Astronomers also use spectroscopic readouts to determine if a star's light has shifted from its normal position. For instance, imagine an absorption spectrum with a

few black spectral lines spaced at precise distances from each other, which indicate a particular fingerprint pattern of an element obtained from starlight. Further suppose that each of these lines was shifted from their normal fingerprint position exactly the same distance towards colors of longer wavelengths. Since the color with the longest wavelength is red, the spectral lines are said to have "redshifted." They would have longer wavelengths and lower frequencies than the normal fingerprint spectrum of that element. On the other hand, if the spectral lines were shifted from their normal fingerprint positions exactly the same distance towards colors of shorter wavelengths, then the starlight would be said to have "blueshifted," since the color with the shortest wavelength is blue.

What causes starlight to redshift? Is it a Doppler effect? Is it the result of the expansion of the universe? Perhaps it is the consequence of something else? The way the first question has been historically answered has significantly impacted this century's astronomy, cosmological theories, and understanding of the universe.

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