Appendix A
The Return of a Static Universe and the End of Cosmology

Lawrence M. Krauss and Robert J. Scherrer

Abstract We demonstrate that as we extrapolate the current CDM universe forward in time, all evidence of the Hubble expansion will disappear, so that observers in our "island universe" will be fundamentally incapable of determining the true nature of the universe, including the existence of the highly dominant vacuum energy, the existence of the CMB, and the primordial origin of light elements. With these pillars of the modern Big Bang gone, this epoch will mark the end of cosmology and the return of a static universe. In this sense, the coordinate system appropriate for future observers will perhaps fittingly resemble the static coordinate system in which the de Sitter universe was first presented.

Shortly after Einstein's development of general relativity, the Dutch astronomer Willem de Sitter proposed a static model of the universe containing no matter, which he thought might be a reasonable approximation to our low-density universe. One can define a coordinate system in which the de Sitter metric takes a static form by defining de Sitter spacetime with a cosmological constant Λ as a four-dimensional hyperboloid $\mathcal{S}_\Lambda : \eta_{AB}\xi^A\xi^B = -R^2$, $R^2 = 3\Lambda^{-1}$ embedded in a $5d$ Minkowski spacetime with $\mathrm{d}s^2 = \eta_{AB}\mathrm{d}\xi^A\mathrm{d}\xi^B$, and $(\eta_{AB}) = \mathrm{diag}(1,-1,-1,-1,-1)$, $A, B = 0,\ldots,4$. The static form of the de Sitter metric is then

$$\mathrm{d}s_s^2 = (1 - r_s^2/R^2)\mathrm{d}t_s^2 - \frac{\mathrm{d}r_s^2}{1 - r_s^2/R^2} - r_s^2\mathrm{d}\Omega^2,$$

L.M. Krauss (✉)
Department of Physics, Case Western Reserve University, Cleveland, OH 44106, USA

Department of Physics & Astronomy, Vanderbilt University, Nashville, TN 37235, USA
e-mail: krauss@cwru.edu

R.J. Scherrer
Department of Physics & Astronomy, Vanderbilt University, Nashville, TN 37235, USA
e-mail: robert.scherrer@vanderbilt.edu

F. Adams, T. Buchert, L. Mersini-Houghton, Founding Editor: F. Nekoogar,
Cosmic Update: Dark Puzzles. Arrow of Time. Future History, Multiversal Journeys,
DOI 10.1007/978-1-4419-8294-0,

which can be obtained by setting $\xi^0 = (R^2 - r_s^2)^{1/2} \sinh(t_s/R)$, $\xi^1 = r_s \sin\theta \cos\varphi$, $\xi^2 = r_s \sin\theta \sin\varphi$, $\xi^3 = r_s \cos\theta$, and $\xi^4 = (R^2 - r_s^2)^{1/2} \cosh(t_s/R)$. In this case, the metric only corresponds to the section of de Sitter space within a cosmological horizon at $R = r - s$.

In fact de Sitter's model was not globally static, but eternally expanding, as can be seen by a coordinate transformation which explicitly incorporates the time dependence of the scale factor $R(t) = \exp(Ht)$. While spatially flat, it actually incorporated Einstein's cosmological term, which is of course now understood to be equivalent to a vacuum energy density, leading to a redshift proportional to distance.

The de Sitter model languished for much of the last century, once the Hubble expansion had been discovered, and the cosmological term abandoned. However, all present observational evidence is consistent with a ΛCDM flat universe consisting of roughly 30% matter (both Dark Matter and baryonic matter) and 70% Dark Energy [1–3], with the latter having a density that appears constant with time. All cosmological models with a nonzero cosmological constant will approach a de Sitter universe in the far future, and many of the implications of this fact have been explored in the literature [4–13].

Here we re-examine the practical significance of the ultimate de Sitter expansion and point out a new eschatological physical consequence: from the perspective of any observer within a bound gravitational system in the far future, the static version of de Sitter space outside of that system will eventually become the appropriate physical coordinate system. Put more succinctly, in a time comparable to the age of the longest lived stars, observers will not be able to perform any observation or experiment that infers either the existence of an expanding universe dominated by a cosmological constant, or that there was a hot Big Bang. Observers will be able to infer a finite age for their island universe, but beyond that cosmology will effectively be over. The static universe, with which cosmology at the turn of the last century began, will have returned with a vengeance.

Modern cosmology is built on integrating general relativity and three observational pillars: the observed Hubble expansion, detection of the cosmic microwave background radiation, and the determination of the abundance of elements produced in the early universe. We describe next in detail how these observables will disappear for an observer in the far future, and how this will be likely to affect the theoretical conclusions one might derive about the universe.

A.1 The Disappearance of the Hubble Expansion

The most basic component of modern cosmology is the expansion of the universe, firmly established by Hubble in 1929. Currently, galaxies and galaxy clusters are gravitationally bound and have dropped out of the Hubble flow, but structures on larger length scales are observed to obey the Hubble expansion law. Now consider what happens in the far future of the universe. Both analytic [7] and numerical [10] calculations indicate that the Local Group remains gravitationally bound in the face of the accelerated Hubble expansion. All more distant structures will be driven outside of the de Sitter event horizon in a timescale on the order of 100 billion years ([4], see also [8, 9]). While objects will not be observed to cross the event horizon, light from them will be exponentially redshifted, so that within a time frame comparable to the longest lived main sequence stars all objects outside of our local cluster will truly become invisible [4].

Since the only remaining visible objects will in fact be gravitationally bound and decoupled from the underlying Hubble expansion, any local observer in the far future will see a single galaxy (the merger product of the Milky Way and Andromeda and other remnants of the Local Group) and will have no observational evidence of the Hubble expansion. Lacking such evidence, one may wonder whether such an observer will postulate the correct cosmological model. We would argue that in fact, such an observer will conclude the existence of a static "island universe," precisely the standard model of the universe c. 1900.

This will be true in spite of the fact that the dominant energy in this universe will not be due to matter, but due to Dark Energy, with $\rho_M/\rho_\Lambda \sim 10^{-12}$ inside the horizon volume [9]. The irony, of course, is that the denizens of this static universe will have no idea of the existence of the Dark Energy, much less of its magnitude, since they will have no probes of the length scales over which Λ dominates gravitational dynamics. It appears that Dark Energy is undetectable not only in the limit where $\rho_\Lambda \ll \rho_M$, but also when $\rho_\Lambda \gg \rho_M$.

Even if there were no direct evidence of the Hubble expansion, we might expect three other bits of evidence, two observational and one theoretical, to lead physicists in the future to ascertain the underlying nature of cosmology. However, we next describe how this is unlikely to be the case.

A.2 Vanishing CMB

The existence of a Cosmic Microwave Background was the key observation that convinced most physicists and astronomers that there was in fact a hot big bang, which essentially implies a Hubble expansion today. But even if skeptical observers in the future were inclined to undertake a search for this afterglow of the Big Bang, they would come up empty-handed. At $t \approx 100$ Gyr, the peak wavelength of the cosmic microwave background will be redshifted to roughly $\lambda \approx 1$ m, or a frequency of roughly 300 MHz. While a uniform radio background at this frequency would in principle be observable, the intensity of the CMB will also be redshifted by about 12 orders of magnitude. At much later times, the CMB becomes unobservable even in principle, as the peak wavelength is driven to a length larger than the horizon [4]. Well before then, however, the microwave background peak will redshift below the plasma frequency of the interstellar medium, and so will be screened from any observer within the galaxy. Recall that the plasma frequency is given by

$$\nu_p = \left(\frac{n_e e^2}{\pi m_e}\right)^{1/2},$$

where n_e and m_e are the electron number density and mass, respectively. Observations of dispersion in pulsar signals give [14] $n_e \approx 0.03\ \mathrm{cm}^{-3}$ in the interstellar medium, which corresponds to a plasma frequency of $\nu_p \approx 1$ kHz, or a wavelength of $\lambda_p \approx 3 \times 10^7$ cm. This corresponds to an expansion factor $\sim 10^8$ relative to the present-day peak of the CMB. Assuming an exponential expansion, dominated by Dark Energy, this expansion factor will be reached when the universe is less than 50 times its present age, well below the lifetime of the longest-lived main sequence stars.

After this time, even if future residents of our island universe set out to measure a universal radiation background, they would be unable to do so. The wealth of information about early universe cosmology that can be derived from fluctuations in the CMB would be even further out of reach.

A.3 General Relativity Gives No Assistance

We may assume that theoretical physicists in the future will infer that gravitation is described by general relativity, using observations of planetary dynamics, and ground-based tests of such phenomena as gravitational time dilation. Will they then not be led to a Big Bang expansion, and a beginning in a Big Bang singularity, independent of data, as Lemaitre was? Indeed, is not a static universe incompatible with general relativity?

The answer is no. The inference that the universe must be expanding or contracting is dependent upon the cosmological hypothesis that we live in an isotropic and homogeneous universe. For future observers, this will manifestly not be the case. Outside of our local cluster, the universe will appear to be empty and static. Nothing is inconsistent with the temporary existence of a non-singular isolated self-gravitating object in such a universe, governed by general relativity. Physicists will infer that this system must ultimately collapse into a future singularity, but only as we presently conclude our galaxy must ultimately coalesce into a large black hole. Outside of this region, an empty static universe can prevail.

While physicists in the island universe will therefore conclude that their island has a finite future, the question will naturally arise as to whether it had a finite beginning. As we next describe, observers will in fact be able to determine the age of their local cluster, but not the nature of the beginning.

A.4 Polluted Elemental Abundances

The theory of Big Bang Nucleosynthesis reached a fully developed state [15] only after the discovery of the CMB (despite early abortive attempts by Gamow and his collaborators [16]). Thus, it is unlikely that the residents of the static universe would have any motivation to explore the possibility of primordial nucleosynthesis. However, even if they did, the evidence for BBN rests crucially on the fact that relic abundances of deuterium remain observable at the present day, while helium-4 has been enhanced by only a few percent since it was produced in the early universe. Extrapolating forward by 100 Gyr, we expect significantly more contamination of the helium-4 abundance, and concomitant destruction of the relic deuterium. It has been argued [17] that the ultimate extrapolation of light elemental abundances, following many generations of stellar evolution, is a mass fraction of helium given by $Y = 0.6$. The primordial helium mass fraction of $Y = 0.25$ will be a relatively small fraction of this abundance. It is unlikely that much deuterium could survive this degree of processing. Of course, the current "smoking gun" deuterium abundance is provided by Lyman-α absorption systems, back-lit by QSOs (see, e.g., [18]). Such systems will be unavailable to our observers of the future, as both the QSOs and the Lyman-α systems will have redshifted outside of the horizon.

Astute observers will be able to determine a lower limit on the age of their system, however, using standard stellar evolution analyses of their own local stars. They will be able to examine the locus of all stars and extrapolate to the oldest such stars to estimate a lower bound on the age of the galaxy. They will be able to determine an upper limit as well, by determining how long it would take for all of the observed helium to be generated by stellar nucleosynthesis. However, without any way to detect primordial elemental abundances, such as the aforementioned possibility of measuring deuterium in distant intergalactic clouds that currently absorb radiation from distant quasars and allow a determination of the deuterium abundance in these pre-stellar systems, and with the primordial helium abundance dwarfed by that produced in stars, inferring the original BBN abundances will be difficult and probably not well motivated.

Thus, while physicists of the future will be able to infer that their island universe has not been eternal, it is unlikely that they will be able to infer that the beginning involved a Big Bang.

A.5 Conclusion

The remarkable cosmic coincidence that we happen to live at the only time in the history of the universe when the magnitude of Dark Energy and Dark Matter densities are comparable has been a source of great current speculation, leading to a resurgence of interest in possible anthropic arguments limiting the value of the vacuum energy (see, e.g., [19]). But this coincidence endows our current epoch with another special feature, namely that we can actually infer the existence of both the cosmological expansion and the Dark Energy. Thus, we live in a very special time in the evolution of the universe: the time at which we can observationally verify that we live in a very special time in the evolution of the universe!

Observers when the universe was an order of magnitude younger would not have been able to discern any effects of Dark Energy on the expansion, and observers when the universe is more than an order of magnitude older will be hard pressed to know that they live in an expanding universe at all, or that the expansion is dominated by Dark Energy. By the time the longest lived main sequence stars are nearing the end of their lives, for all intents and purposes, the universe will appear static, and all evidence that now forms the basis of our current understanding of cosmology will have disappeared.

Note added in proof: After this paper was submitted we learned of a prescient 1987 paper [20], written before the discovery of Dark Energy and other cosmological observables that are central to our analysis, which nevertheless raised the general question of whether there would be epochs in the Universe when observational cosmology, as we now understand it, would not be possible.

Acknowledgment L.M.K. and R.J.S. were supported in part by the Department of Energy.

References

1. L.M. Krauss, M.S. Turner, Gen. Rel. Grav. **27**, 1137 (1995)
2. S. Perlmutter, et al., Astrophys. J. **517**, 565 (1999)
3. A.G. Reiss, et al., Astron. J. **116**, 1009 (1998)
4. L.M. Krauss, G.D. Starkman, Astrophys. J. **531**, 22 (2000)
5. A.A. Starobinsky, Grav. Cosmol. **6**, 157 (2000)
6. E.H. Gudmundsson, G. Bjornsson, Astrophys. J. **565**, 1 (2002)
7. A. Loeb, Phys. Rev. D **65**, 047301 (2002)
8. T. Chiueh, X.-G. He, Phys. Rev. D **65**, 123518 (2002)
9. M.T. Busha, F.C. Adams, R.H. Wechsler, A.E. Evrard, Astrophys. J. **596**, 713 (2003)
10. K. Nagamine, A. Loeb, New Astron. **8**, 439 (2003)
11. K. Nagamine, A. Loeb, New Astron. **9**, 573 (2004)
12. J.S. Heyl, Phys. Rev. D **72**, 107302 (2005)
13. L.M. Krauss, R.J. Scherrer, Phys. Rev. D **75**, 083524 (2007)
14. A.G.G.M. Tielens, in *The Physics and Chemistry of the Interstellar Medium* (Cambridge University Press, Cambridge, 2005)
15. R.V. Wagoner, W.A. Fowler, F. Hoyle, Astrophys. J. **148**, 3 (1967)
16. R.A. Alpher, H. Bethe, G. Gamow, Phys. Rev. **73**, 803 (1948); R.A. Alpher, J.W. Follin, R.C. Herman, Phys. Rev. **92**, 1347 (1953)
17. F.C. Adams, G. Laughlin, Rev. Mod. Phys. **69**, 337 (1997)
18. D. Kirkman, D. Tytler, N. Suzuki, J.M. O'Meara, D. Lubin, ApJ Suppl. **149**, 1 (2003)
19. S. Weinberg, Phys. Rev. Lett. **59**, 2607 (1987); J. Garriga, M. Livio, A. Vilenkin, Phys. Rev. D **61**, 023503 (2000)
20. T. Rothman, G.F.R. Ellis, Observatory **107**, 24 (1987)

Glossary

Anti-DeSitter Space Space-time with constant negative curvature.

Baryonic Matter Known matter (as opposed to Dark Matter).

Big Bang The term is used to refer to the singularity at the beginning of our Universe. The Big Bang theory explains how the Universe is expanding from its initial state.

Big Crunch Reversal of the Big Bang, where the whole Universe collapses to a singularity.

Big Rip A scenario where the acceleration of the expansion increases with time, resulting in a “tearing” apart of the very fabric of spacetime.

Black Hole A region of space-time that is bended inward due to the extreme force of gravity. It traps anything even light that passes its event horizon.

Brown Dwarfs Brown dwarfs are astronomical objects that are too small to sustain hydrogen fusion in their cores.

Chandrasekhar Mass A mass threshold in stellar structures named after the Indian astrophysicist. When the Chandrasekhar mass limit is breached, the degenerate star is too heavy to support itself, and the object blows up in a supernova.

Concordance Model of Cosmology Concordance Model of Cosmology is a homogeneous and isotropic solution of Einstein’s theory of gravitation with a cosmological constant and with vanishing curvature.

Cosmic Microwave Background Remnant E&M radiation from big bang. It is now at a temperature of about 2.7 K (2.7° above absolute zero).

Cosmic Strings These are different objects from strings in string theories. Cosmic strings are theoretical objects that have been developed at the beginning phase of the Universe. Extremely long and narrow but massive, they could be stretched across the Universe.

Cosmic Topology Using topology to construct cosmological models.

Cosmology Study of the cosmos that deals with the origin, the evolution, and the fate of the Universe.

F. Adams, T. Buchert, L. Mersini-Houghton, Founding Editor: F. Nekoogar,
Cosmic Update: Dark Puzzles. Arrow of Time. Future History, Multiversal Journeys,
DOI 10.1007/978-1-4419-8294-0, © Springer Science+Business Media, LLC 2012

Cosmological Constant A term used by Einstein in his general relativity equation for the purpose of counter effecting gravitational attraction. Based on observed acceleration in the expansion of the Universe, it has a small value of the order of $10^{-29}\,\mathrm{g\,cm^{-3}}$.

Cosmological Heat Death A term that refers to a possible state of the Universe in which it expands adiabatically (no new entropy is produced).

Cosmological Principle The strong version states that locally the Universe is isotropic about every point and hence homogeneous. The weak version requires this only for the average distribution on large scales.

Dark Energy Dark Energy is believed to be the vacuum energy with negative pressure in its simplest form that causes the Universe to accelerate. It accounts for about 75% of the matter/energy of the Universe.

Dark Matter A kind of matter that cannot be seen directly and its composition is unknown. However, its gravitational effect can be measured. It responds to gravitational force, but it does not respond to strong, weak, and electromagnetic forces. Dark Matter accounts for 22–25% of the total energy of the Universe.

Dark Matter Halos Large structures that extend far beyond the visible portions of galaxies marked by stars, gas, and other forms of ordinary matter.

De Sitter Space In homogeneous cosmology this term is also used to refer to a flat space with no matter and a cosmological constant

DeSitter Universe If the Universe ends up in a cosmic heat death, cold and empty of structure, maintaining its entropy and temperature at constant values eternally. Such a Universe is known as a DeSitter Universe.

Doppler Effect The shift in frequency of a wave (to a higher frequency, when its source is moving toward a receiver; and to a lower frequency, when the source is moving away from the receiver) for an observer moving relative to the source of the wave.

Entropy A measure of the disorder or chaos of a closed system.

Event Horizon An event horizon is a hyper-surface in space-time beyond which events cannot affect an outside observer.

Exotic Material Hypothetical material inside of a wormhole which has negative average energy density.

Flatness Problem One of the three problems associated with the standard models of cosmology. The problem has to do with the basic question, why the Universe is close to being spatially flat.

Friedmann–Lemaitre–Robertson–Walker Models Spatially homogeneous and isotropic models of cosmology.

General Theory of Relativity It formulates how gravity bends space-time, and it is used to explain and understand the large-scale structure of the Universe.

Halos It is believed that galaxies and galaxy clusters are embedded in giant halos of Dark Matter.

Hawking Effect A slow quantum mechanical process that ultimately leads to the decay of black holes. Through quantum effects, virtual particles are created near the event horizon of a black hole. Although such particles only live for a short time, the tidal stretching force, which is enormous near a black hole, does work on them while they remain in existence. If the work done on the particle – by the tidal force – is large enough, the particle is promoted from virtual existence to "real" existence. The particle can then leave the black hole and is thus effectively emitted by the hole.

Hawking Radiation Radiation produced by the Hawking effect.

Hawking Temperature The Hawking temperature of a black hole is given by the expression:

$$T_{\text{bh}} = \frac{h\mathrm{C}^3}{8\pi k G M_{\text{bh}}}$$

where M_{bh} is the mass of the object. Note that this temperature is extremely small: $T_{\text{bh}} \approx 6 \times 10^{-8}$ K for a black hole with one solar mass.

Homogeneous Everywhere the same.

Horizon Problem One of the three problems associated with the early models of bing bang cosmology. The problem has to do with the causal connection of different parts of the Universe.

Hubble Constant *H* The constant in Hubble's law which is used to calculate the size and age of the Universe.

Hubble Expansion Law Simply stated by $V = HD$ equation, where V is the recession velocity of objects such as galaxies, H is the Hubble constant, and D is distance from Earth.

Hubble Time Hubble time is comparable to the current age of the Universe.

Inflationary Cosmology It states that the Universe (the space) went through exponential expansion very early after the big bang.

Isotropic The same in every direction. In cosmology, it means the Universe looks the same in every direction.

LISA Laser Interferometer Space Antenna. http://lisa.nasa.gov/.

LHC Large Hadron Collider. It is the world's largest and highest energy particle accelerator. A circular (27 km in circumference) particle accelerator (proton–proton collider) laboratory at CERN in Geneva.

MACHOS Massive Astrophysical Compact Halo Objects.

Multiverse This term is used to refer to Multi-Universes.

Nebulae A Nebulae is an interstellar cloud of dust and gases. This term was also used in early observations and they turned out to be other galaxies beyond our Milky Way galaxy.

Neutrino An elementary particle that is electrically neutral (does not carry electric charge).

Neutron Stars The star, with roughly the mass of the Sun and a radius of only 10 km, becomes essentially one gigantic nucleus, with most of the electrons and protons combining to make neutrons. Hence the name "neutron stars."

No Hair Theorem A constraint which states that only three properties of a black hole can be observed outside its event horizon. (The black hole mass. The spin of the black hole. The electric charge of the black hole).

Planck Length A quantity associated with quantum gravity. It is about 10^{-35} cm.

Planck Mass A quantity associated with quantum gravity. It is about 10^{-8} kg.

Planck Time A quantity associated with quantum gravity. It is the time it takes for light to travel a Planck length interval which is about 10^{-42} s.

Quantum Cosmology A branch of cosmology that uses the laws of quantum mechanics to study the cosmos.

Quantum Gravity A theory that unifies General Theory of Relativity with quantum mechanics under one single framework.

Red Dwarfs Stars belonging to the smallest class of stars which live much longer compared to other stars are known as “M stars” or “red dwarfs.”

Red Giant A star of low or intermediate mass will become a Red Giant in its late phase of stellar evolution. The Sun will become a red giant in about seven billion years from now.

Second Law of Thermodynamics Entropy of a closed system is always greater than or equal to 0. It cannot decrease.

Smoothness Problem One of the three problems associated with the standard models of cosmology. The problem has to do with the basic question why the matter is uniformly distributed in the Universe.

Singularity A point in space-time where its curvature becomes infinite. Big Bang is an example of a singularity.

Special Theory of Relativity It states that laws of nature are the same for all observers regardless of how they move. Also, it describes that space and time are connected and no longer individually absolute.

Standard Model of Cosmology Standard model of Cosmology consists of the following theories and models: General Theory of Relativity, Dark Matter, Dark Energy, initial conditions at Big Bang, and Standard model of particle physics.

Stellar Black Holes These objects have masses in the range of 10 to perhaps 100 Suns.

Supermassive Back Holes Astronomical observations clearly show that almost every large galaxy contains a monster black hole at its core. These black holes come in a range of masses, from about one million to one billion times the mass of our Sun.

Supernova/Supernovae A supernova is a nuclear stellar explosion at the end of the star’s life.

Thermodynamic Arrow of Time The thermodynamic arrow of time is based on the Second Law of Thermodynamics that in a closed/isolated system, entropy increases with time.

Thermodynamical Equilibrium A system with maximum amount of entropy.

Topology A branch of mathematics that deals with spatial properties that are preserved under continuous deformations of objects.

Uncertainty Principle One of the basic principles of quantum mechanics developed by W. Heisenberg. It formulates that one cannot precisely specify the values of two conjugate terms such as position-momentum or time-energy.

White Dwarfs A white dwarf is a very dense small star. Approximately 997 of every 1,000 stars will turn into white dwarfs upon their death. These stellar remnants typically retain somewhat less mass than that of our Sun, but they are much smaller in radius and are one million times denser.

WIMPS Weakly Interacting Massive Particles.

White Hole The time reversal of a black hole. Big bang is an example of a white hole. A theoretical region of space-time where matter erupts but cannot enter the region.

About the Authors

Fred C. Adams is Professor of Physics at The University of Michigan, Ann Arbor. He received his PhD in Physics from the University of California, Berkeley, in 1988. For his PhD dissertation research, he received the Robert J. Trumpler Award from the Astronomical Society of the Pacific. After serving as a postdoctoral research fellow at the Harvard-Smithsonian Center for Astrophysics (Cambridge, MA), he joined the faculty in the Physics Department at the University of Michigan (Ann Arbor, MI) in 1991. Adams was promoted to Associate Professor with tenure in 1996, and to Full Professor in 2001. He is the recipient of the Helen B. Warner Prize from the American Astronomical Society and the National Science Foundation Young Investigator Award. He has also been awarded both the Excellence in Education Award and the Excellence in Research Award from the College of Literature, Arts, and Sciences at the University of Michigan. In 2002, he was given The Faculty Recognition Award from the University of Michigan. He has recently been named to as a Senior Fellow for the Michigan Society of Fellows. Professor Adams works in the general area of theoretical astrophysics with a focus on the study of star formation and cosmology. He is internationally recognized for his work on the radiative signature of the star formation process, the dynamics of circumstellar disks, and the physics of molecular clouds. His recent work in star formation includes the development of a theory for the initial mass function for forming stars and studies of extra-solar planetary systems. In cosmology, he has studied many aspects of the inflationary universe, cosmological phase transitions, magnetic monopoles, cosmic rays, anti-matter, and the nature of cosmic background radiation fields. His recent work in cosmology includes a treatise on the long-term fate and evolution of the universe and its constituent astrophysical objects.

Thomas Buchert is Professor of Cosmology at the University Claude Bernard in Lyon, France. He is a leading expert in the research field on inhomogeneous cosmological models. He worked as Research Associate at the Max-Planck-Institute for Astrophysics in Garching, Germany, in the period 1984–1995 during which he obtained his PhD in Theoretical Physics from the University of Munich in 1988. During the period 1988–1994, he took several short-term visiting positions in

F. Adams, T. Buchert, L. Mersini-Houghton, Founding Editor: F. Nekoogar,
Cosmic Update: Dark Puzzles. Arrow of Time. Future History, Multiversal Journeys,
DOI 10.1007/978-1-4419-8294-0, © Springer Science+Business Media, LLC 2012

Europe being Member of the European Cosmology Network. His research was focussed on cosmological structure formation theories, where the heart of this work was defined within a 5 years project of the German Science Foundation leading to his Habilitation in Astronomy, received from the University of Munich in 1994. He organized exchange projects with France and Spain, and he was active in the Max-Planck exchange programme with the Chinese Academy of Sciences. In 1995, he obtained the degree Lecturer at the University of Munich. Since then until 2006 he worked as Research Associate at the Technical University in Munich, and as a Lecturer in Theoretical Physics and Cosmology. During that time he was leading a research group within a project on Astroparticle Physics as PI on morphological statistics of cosmic structure. From 1998 until 2006 he took several long-term visiting positions as Associated Member of Personnel at CERN in Geneva, Switzerland, as Tomalla Visiting Professor at University of Geneva, as Center of Excellence Researcher at the National Astronomical Observatory in Tokyo, Japan, and as Monkasho Invited Professor at the University of Tokyo at the Research Center for the Early Universe, during which he also worked as Visiting Professor at Tohoku University in Sendai, Japan, and the Tokyo Institute of Technology. During the summer term 2006, he took a temporary Chair as Full Professor in Theoretical Physics at the University of Bielefeld, Germany. Since then he regularly worked at the Observatory of Paris in France, became Staff Member at the Observatory of Lyon, and Full Professor at the University Claude Bernard, Lyon, in 2007. He gives courses on gravitational theories, mathematical physics, kinetic theory, and cosmology within the Master Programme at École Normale Supérieure in Lyon. Since 2010, he is head of a large team dealing with galaxy physics, simulations, instrumentation projects, and theoretical cosmology, and he is PI of a collaboration on Dark Energy and Dark Matter. Professor Buchert works in the areas of theoretical, observational, and statistical cosmology with a focus on the understanding of global properties of world models. His research interests also include Riemann–Cartan geometry, integral geometry, and nontrivial topologies of spaceforms. He is internationally recognized for innovations on the morphological analysis of galaxy catalogues and Cosmic Microwave Background maps, on the foundations of the Lagrangian theory of structure formation, and for a set of equations governing the average evolution of cosmological models in general relativity and their implications for an explanation of the Dark Energy and Dark Matter problems.

Laura Mersini-Houghton is Professor of Cosmology and Theoretical Physics at UNC-Chapel Hill. She did her bachelor's degree at the University of Tirana. Then she received a Fulbright Scholarship to study at the University of Maryland-College Park, where she received her Master's degree in 1997. She then moved to the University of Wisconsin–Milwaukee where she finished her Ph.D. under the mentorship of L. Parker in 2000. She was awarded a postdoctoral research grant at Scuola Normale in Pisa during 2000–2002. She joined the faculty at the University of North-Chapel Hill in 2004 and was promoted as Associate Professor with tenure in 2008.

Her main research areas are foundational issues related to the early universe and the current acceleration of the universe. She proposed a theory of the initial conditions of the universe soon after the discovery of the landscape of string theory around 2004. Her theory assumes that before the Big Bang, the universe is a wavefunction propagating in a landscape of possible Big Bangs. As such the theory strongly advocates the existence of a multiverse. It is the only theory that shows why the universe(s) can only start at high energies. Three of the predicted signatures in the sky of this theory for the birth of the universe from the landscape have been tested recently. For this reason, her theory on how the universe started has received worldwide media attention and has been featured in many science magazines and TV programs such as BBC-Horizon, National Geographic, and "Through the wormhole: with Morgan Freeman."

Her previous work on the current acceleration of the universe explored the possibility that the fabric of spacetime at very short distances, which is the realm of quantum gravity, obeys a different relation between the energy and velocity of modes. As the universe grows, this fabric gets stretched (redshifted) and so do the short distance modes along with it. Since these modes are not short any longer, they contribute to the Dark Energy in the universe. This process of replenishing the energy of the universe by the short distance modes that enter it due to being redshifted continues ad infinitum.

Index

F. Adams, T. Buchert, L. Mersini-Houghton, Founding Editor: F. Nekoogar,
Cosmic Update: Dark Puzzles. Arrow of Time. Future History, Multiversal Journeys,
DOI 10.1007/978-1-4419-8294-0,