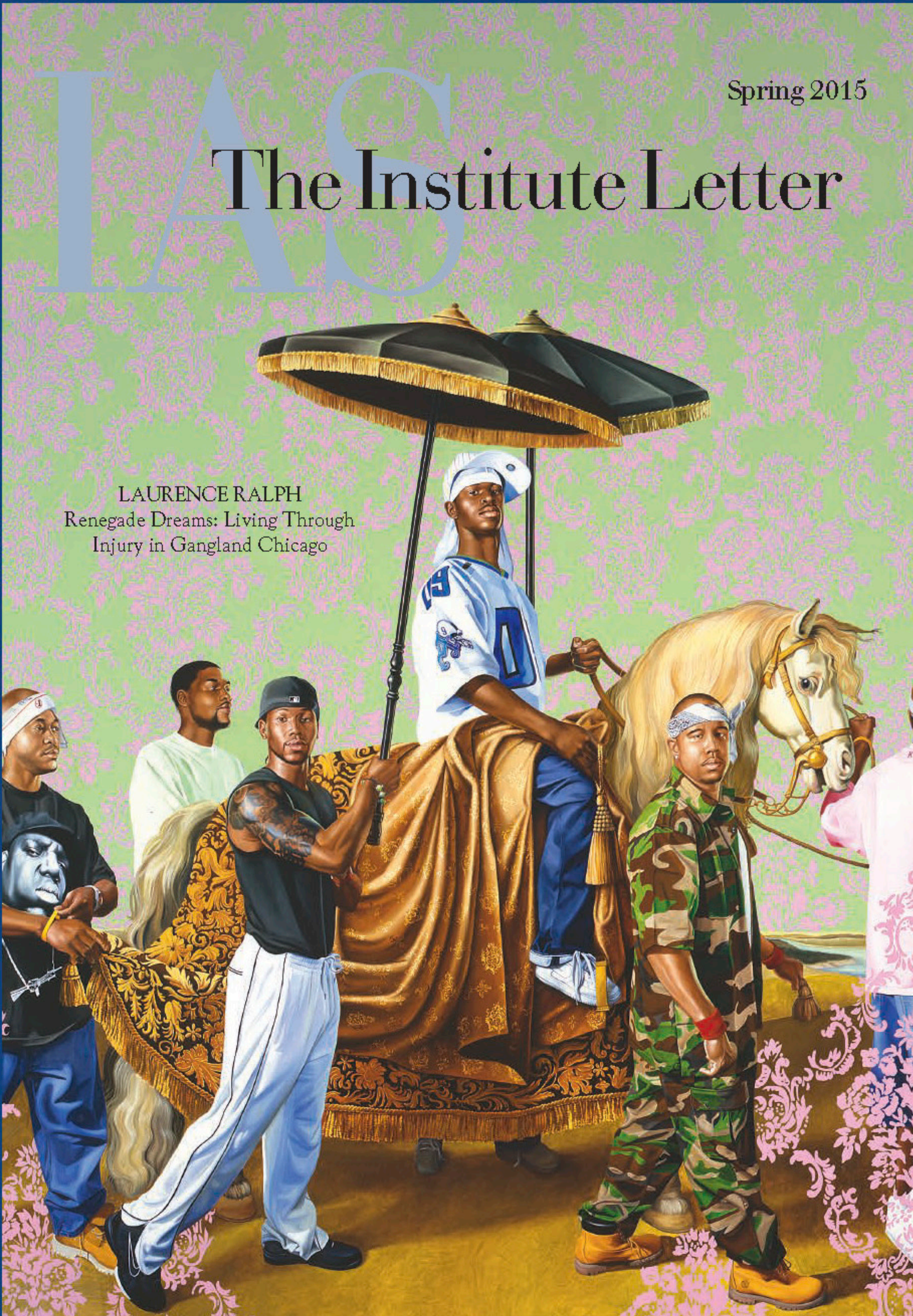
IAS

Spring 2015

The Institute Letter



LAURENCE RALPH
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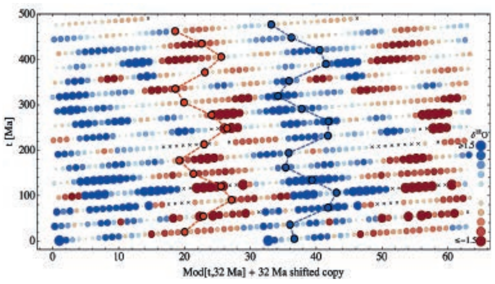
The Birth of a Theorem

The Institute Letter

Institute for Advanced Study Spring 2015

Sights from a Field Trip in the Milky Way: From Paleoclimatology to Dark Matter

How might climate be influenced by cosmic rays?



NIR SHAVIV

Our galactic journey imprinted in the climate—when Earth's temperature (red dots warm, blue dots cold) is plotted as a function of time (vertical axis) and as a function of time folded over a 32-million-year period (horizontal axis), the 32-million-year oscillation of the solar system relative to the galactic plane is evident.

BY NIR SHAVIV

In 1913, Victor Hess measured the background level of atmospheric ionization while ascending with a balloon. By doing so, he discovered that Earth is continuously bathed in ionizing radiation. These cosmic rays primarily consist of protons and heavier nuclei with energies between their rest mass and a trillion times larger. In 1934, Walter Baade and Fritz Zwicky suggested that cosmic rays originate from supernovae, the explosive death of massive stars. However, only in 2013 was it directly proved, using gamma-ray observations with the Fermi satellite, that cosmic rays are indeed accelerated by supernova remnants. Thus, the amount of ionization in the lower atmosphere is almost entirely governed

(Continued on page 14)

The Necessity of a Historical Approach to Islamic Theology

Tracing modern Islamic thought to the Middle Ages

When Professor Sabine Schmidtke and Hassan Ansari, an Iranian national, met more than a decade ago in Tehran, Ansari was a student of the traditional religious system in Qum and Tehran (the "Hawza"). Ansari had read Schmidtke's doctoral thesis *The Theology of al-ʿAllāma al-Ḥillī (d. 726/1325)*, which was translated into Persian and published in Iran in 1999. Schmidtke's scholarship changed Ansari's approach to Islamic sources and was one of the reasons why he became interested in historical studies on Islamic theology. "The historical approach is not only useful, it is necessary," says Ansari. "I talk now as a Muslim scholar. We need to have this kind of historical studies to change our approach to our own intellectual and legal tradition and its holy texts."

DAN KING

Hassan Ansari (right) with Sabine Schmidtke

What makes Ansari a particularly exceptional scholar is his combination of Western and traditionalist Islamic training. In the "Hawza" in Qum and Tehran, he

(Continued on page 5)

Lens of Computation on the Sciences

What do quantum interference, flocking of birds, Facebook communities, and stock prices have in common?

Many natural and social phenomena may be viewed as inherently computational; they evolve patterns of information that can be described algorithmically and studied through computational models and techniques. A workshop on the computational lens, organized by Avi Wigderson, Herbert H. Maass Professor in the School of Mathematics, highlighted the state-of-art and future challenges of this interaction of computational theory with physics, social sciences, economics, and biology.

Leslie Valiant, T. Jefferson Coolidge Professor of Computer Science and Applied Mathematics in the School of Engineering and Applied Sciences at Harvard University, spoke on the scientific question of how to determine the molecular mechanism of biological evolution, to a level of specificity that it can be simulated by a computer, and to understand why this mechanism can do the remarkable things that it has done within the time that has been available. Valiant's talk addressed how the tools needed to approach this come from machine learning, the field that studies how mechanisms that achieve complex functionality can arise by a process of adaptation rather than design.

Tim Roughgarden, Associate Professor of Computer Science and (by courtesy) Management Science and Engineering at Stanford University, discussed a number of tools that theoretical computer science offers to reason about economic problems in novel ways. For example, complexity theory sheds new light on the "bounded rationality" of decision-makers; approximation guarantees, originally developed to analyze heuristics, can be usefully applied to Nash equilibria; and computationally efficient algorithms are an essential ingredient to modern, large-scale auction designs.

Jon Kleinberg, Tisch University Professor in the Departments of Computer Science and Information Science at Cornell University, spoke about computational phenomena in social interaction. With an increasing amount of social interaction taking place in the digital domain, and often in public online settings, we are accumulating enormous amounts of data about phenomena that were once essentially invisible to us: the collective behavior and social interactions of hundreds of millions of people, recorded at unprecedented levels of scale and resolution. Kleinberg reviewed how modeling and analyzing these phenomena computationally offers new insights into the design of online applications, as well as new perspectives on fundamental questions in the social sciences.

Scott Aaronson, Associate Professor of Electrical Engineering and Computer Science at the Massachusetts Institute of Technology, discussed the quest to understand the limits of efficient computation in the physical universe, and how that quest has been giving us new insights into physics over the last two decades. He explored the following questions: Can scalable quantum computers be built? Can they teach us anything new about physics? Is there some new physical principle that explains why they cannot be built? What would quantum computers be good for? Can quantum computing help us resolve which interpretation of quantum mechanics is the right one? Which systems in nature can be universal computers, and which cannot? Aaronson also described a striking recent application of computational complexity theory to the black hole information loss problem. ■

Recommended Viewing: Conference talks may be viewed at https://video.ias.edu/computationconference/2014/1122.

News of the Institute Community

ANGELOS CHANIOTIS, Professor in the School of Historical Studies, has received an Anneliese Maier Research Award from the Alexander von Humboldt Foundation. Additionally, Chaniotis has been appointed to the Board of Directors of the Alexander S. Onassis Public Benefit Foundation.

Brill Academic Publishers has published *Manufacturing a Past for the Present: Forgery and Authenticity in Medievalist Texts and Objects in Nineteenth-Century Europe* (2014). Edited by PATRICK J. GEARY, Professor in the School of Historical Studies, János M. Bak, and Gábor Klaniczay, this series of essays explores the volatile notion of authenticity in nineteenth-century Europe.

JONATHAN ISRAEL, Andrew W. Mellon Professor in the School of Historical Studies, has received a 2015 PROSE award for *Revolutionary Ideas: An Intellectual History of the French Revolution from The Rights of Man to Robespierre* (Princeton University Press, 2014).

Oxford University Press has published *Towards a Better Global Economy: Policy Implications for Citizens Worldwide in the 21st Century* (2014) by DANI RODRIK, Albert O. Hirschman Professor in the School of Social Science, and six additional authors. The book examines the factors that are most likely to facilitate the process of beneficial economic growth in low-, middle-, and high-income countries.

SABINE SCHMIDTKE, Professor in the School of Historical Studies, is the founding editor-in-chief of a new peer-reviewed journal, *Intellectual History of the Islamicate World* (Brill), that bridges the disciplines of Islamic, Jewish, and Eastern Christian Studies.

Berghahn Books has published *Clausewitz in His Time: Essays in the Cultural and Intellectual History of Thinking about War* (2014) by PETER PARET, Professor Emeritus in the School of Historical Studies. The work follows the career of Prussian general and military theorist Carl von Clausewitz (1780–1831) and explores the late-eighteenth-century thought that helped shape his analytic method.

MARTIN L. LEIBOWITZ, Vice Chairman of the Institute's Board, was awarded the 2014 IAQF/SunGard Financial Engineer of the Year Award in recognition of his contributions to quantitative finance.

DAVID M. RUBENSTEIN, Institute Trustee, was awarded the Museum of American Finance's 2015 Whitehead Award for Distinguished Public Service and Financial Leadership. Rubenstein also received the Susan G. Komen Breast Cancer Foundation's Lifetime Achievement Award in recognition of his support of research and global and community initiatives.

CHARLES SIMONYI, Chairman of the Institute's Board, has been named a Stanford University Engineering Hero for creating the Bravo WYSIWYG text editor in 1974, when he was at Xerox PARC, and for his role as chief architect of Microsoft Word, Excel, and other widely used programs.

MANDUHAI BUYANDELGER, Member in the School of Social Science, has received the 2014 Francis L.K. Hsu Book Prize from the Society for East Asian Anthropology for *Tragic Spirits: Shamanism, Memory, and Gender in Contemporary Mongolia* (Chicago University Press, 2013).

RUSH HOLT, Director's Visitor, has been named Chief Executive Officer of the American Association for the Advancement of Science.

The 2015 Dannie Heineman Prize in Astrophysics was awarded to DAVID SPERGEL, Visitor in the School of Natural Sciences, and MARC KAMIONKOWSKI, former Member (1991–95) in School of Mathematics, for their investigation of the flunctuations of the cosmic microwave background—work done while Kamionkowski was a Member. Also, Kamionkowski was named a 2014 Simons Investigator.

RASHID SUNYAEV, Visiting Professor in the School of Natural Sciences, has received the Eddington Medal from the Royal Astronomical Society for predicting the kinetic Sunyaev-Zeldovich effect, which is used to measure the velocity of galaxy clusters relative to the cosmic background radiation. Sunyaev was also named the first recipient of the Zeldovich Gold Medal from the Russian Academy of Sciences.

The New Horizons in Physics Prize was awarded to HORACIO CASINI and MARINA HUERTA, former Visitors (2014) in the School of Natural Sciences, for fundamental ideals about entropy in quantum field theory and quantum gravity, and PHILIP SCHUSTER and NATALIA TORO, former Members (2011) in the School, for their work on pioneering the simplified models framework for new physics searches at the Large Hadron Collider.

STANLEY DESER, former Member (1953–55, 1993–94) in the School of Natural Sciences, was awarded the Einstein Society's 2015 Einstein Medal for his contributions to general relativity, in particular the development of ADM formalism.

MAYKE BRECHTJE DE JONG, former Member (2012) in the School of Historical Studies, has received a Research Award from the Alexander von Humboldt Foundation to complete the book she began at IAS on the interconnectedness of public and religious domains in late antiquity and the early Middle Ages.

SUBHASH KHOT, former Member (2003–04) in the School of Mathematics, has received the 2014 Rolf Nevanlinna Prize from the International Mathematical Union for outstanding contributions in mathematical aspects of information sciences.

JEFFREY LAGARIAS, former Visitor (2000, 2001) in the School of Mathematics, received the AMS 2015 Levi L. Conant Prize jointly with Chuanming Zong for their article "Mysteries in Packing Regular Tetrahedra" (*Notices of the AMS*, December 2012).

ROBERT K. LAZARSFELD, former Member (1981–82) in the School of Mathematics, was awarded the AMS 2015 Leroy P. Steele Prize for Mathematical Exposition for his work *Positivity in Algebraic Geometry I and II* (Springer, 2004).

JOEL LEBOWITZ, former Member in the Schools of Mathematics (2001–02, 2006, 2013–14) and Natural Sciences (1980–81), has received the 2014 Grande Médaille from the Académie des Sciences of the Institut de France, their highest honor.

BRICE MÉNARD, former Member (2003–06) in the School of Natural Sciences, has been awarded the 2014 David and Lucile Packard Foundation Fellowship for Science and Engineering, which provides flexible funding to a group of scientists and engineers who have demonstrated vision for the future of their fields and for the betterment of society.

VANESSA OGLE, former Member (2013–14) in the School of Social Science, has received the Social Science History Association's President's Book Award for her first book, *Contesting Time: The Global Struggle for Uniformity and Its Unintended Consequences, 1870s–1950s*, forthcoming in fall 2015 from Harvard University Press.

HEE OH, former Visitor (2006) and Member (2002–03) in the School of Mathematics, received the AMS 2015 Ruth Lyttle Satter Prize for her fundamental contributions to the dynamics on homogeneous spaces, discrete subgroups of Lie groups, and applications to number theory.

SAUL PERLMUTTER, former Member (2011) in the School of Natural Sciences, received the Breakthrough Prize in Fundamental Physics, which recognizes major insights into the deepest questions of the universe. JOHN TONRY, former Member (1980–82) in the School, is a member of the High-Z Supernovae Search Team that also won the Breakthrough Prize in Fundamental Physics.

NIKHIL SRIVASTAVA, former Visitor (2012) and Member (2010–11) in the School of Mathematics, won the Society for Industrial and Applied Mathematics' 2014 George Pólya Prize for solving a fifty-year-old problem, the Kadison-Singer conjecture.

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Questions and comments regarding the *Institute Letter* should be directed to Kelly Devine Thomas, Senior Publications Officer, via email at kdthomas@ias.edu or by telephone at (609) 734-8091.

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Recent Gifts in Support of Memberships and Campus Programs at IAS

ERIC AND WENDY SCHMIDT GIVE $5 MILLION

Eric Schmidt, Executive Chairman of Google Inc. and Trustee of the Institute for Advanced Study, and Wendy Schmidt, President of the Schmidt Family Foundation, have donated $5 million to support four Members, known as Schmidt Fellows, across the Schools of Natural Sciences and Mathematics and to support campus programs and promotion. The $5 million gift from the Schmidts is an important contribution to the Campaign for the Institute, which ends on June 30, 2015, and helps to complete the $100 million campaign challenge established by the Simons Foundation and the Charles and Lisa Simonyi Fund for Arts and Sciences.

The Schmidts' gift will support the world's top early-stage talent in mathematics and the natural sciences with the time, space, and conducive environment to push the boundaries of human understanding. It will also be used to promote the Institute's work through the convening of campus programs designed to draw key audiences, including academics, philanthropists, thought leaders, and media outlets.

"Not only does the Institute bring together academics of the highest level, but it is a symbol for the importance of academic freedom and basic research," said Robbert Dijkgraaf, Director and Leon Levy Professor. "This generous gift from Wendy and Eric allows us the freedom and independence to draw exciting young talent and cultivate programs on campus for existing and new audiences." ■


DAN KOMODA

Eric Schmidt hosted an IAS-Google event in February 2014, "Imagining the Future," which explored the frontiers of science and technology.

INFOSYS GIVES $2 MILLION

In October, Infosys and the Institute announced a new endowment fund to support visiting scientists and scholars. The Infosys Fund has been created with a $2 million gift to support two scholars across the Institute's four Schools each year. The Infosys Members will receive support related to all aspects of the academic appointment and community life.

Infosys has a longstanding connection with the Institute through the Infosys Prize, which has recognized several of its former visiting scientists in the subject of mathematical sciences.

"We believe that people, when amplified by technology, knowledge, imagination, and an enriching ecosystem, can achieve incredible things," said Vishal Sikka, Chief Executive Officer and Managing Director of Infosys. "This is the beginning of a human revolution, and institutions like IAS have long served to accelerate it. By mentoring visiting scholars, in both academic and practical terms, the IAS has created yet another avenue to produce advances in knowledge that can change the way we work and live—with wide-ranging impact on global development." ■

Curiosities

Light's Revelations and Mysteries

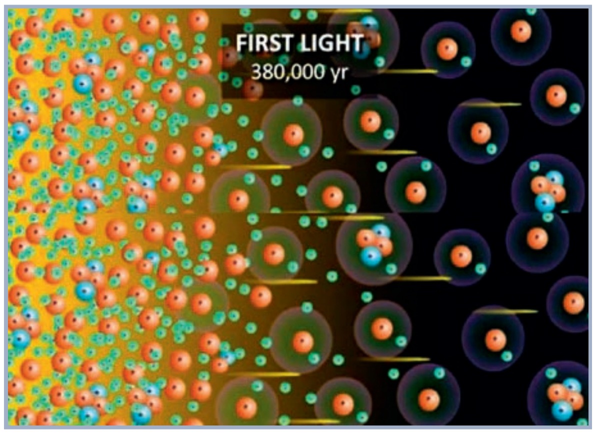
BY ROBBERT DIJKGRAAF

Light is the great unifier. John Wheeler, the beloved Princeton physicist, used to draw the universe as a big capital U with a little eye on one leg, signifying that we, human beings, are the eyes of the universe looking back at itself. The universe after many, many billions of years formed human life on planet Earth, and we use light to observe and understand the universe.

The growing understanding of the nature of light through the centuries is the perfect metaphor for science: it is an eye-opener. Almost 350 years ago, Isaac Newton, as a young man, put a prism in a beam of light and unraveled its various colors. This was the beginning of a long story. Around the year 1800, the astronomer William Herschel was the first to measure the temperature of light. He made the startling discovery that the rainbow does not stop at red, but actually continues, invisibly, as infrared light, which we cannot see but can feel as a sensation of warmth.

What is light? Physics has a simple answer: an electromagnetic wave. Exactly 150 years ago, the Scottish physicist James Clerk Maxwell discovered the laws that describe these waves. I have a T-shirt with these equations and the text "And then there was light." If only Maxwell had patented his equations! It would be enough to finance all research in the world.

Maxwell's theory is the first and finest example of unification: electricity and magnetism bound together in a single formula. There is a good reason his portrait hangs in Einstein's study, together with Michael Faraday's. Suddenly, light was connected to lightning, batteries, and magnets. Now we can add to this radio, television, wireless internet, microwaves, X-rays, and the complete high-tech industry.



Light connects us to the very beginning of the universe. The first light was emitted roughly 380,000 years after the Big Bang, when matter was no longer closely tied together and light could escape. This radiation was detected for the first time fifty years ago this year.

We have learned that the rainbow continues on both ends, in theory even infinitely far. On one end, electromagnetic radiation extends to the very large, from microwaves to the radio waves that curl around the Earth. On the other end, we find the ultraviolet that birds can see, the X-rays that penetrate our bodies, and the gamma rays that can spontaneously produce particles.

Light is the connector between all the physical elements in our universe, and it explains the most basic structures in life. Grass is green because of the way light is absorbed by the chlorophyll molecules in its leaves. Even space and time itself are illuminated by light. One hundred years ago, in November 1915, Einstein discovered his theory of general relativity. He realized that if you put anything—literally anything—in space, space and time will curve, and that gravity manifests itself through these curvatures. The famous 1919 experiment, which proved his theory and made him famous, used a solar eclipse to measure the warping of starlight through the sun's gravitational field.

With modern telescopes, we now see this effect in full glory in the sky. We observe how galaxies act as cosmic lenses and distort the images of stars and other galaxies in the most bizarre ways. But the most dramatic way in which the universe shapes light is through its expansion. Astronomers have discerned this phenomenon by noticing that the colors of distant stars are shifted toward the red. Objects that are moving have different colors—this is known as the Doppler effect—and some of these galaxies move away from us so fast that they are in the deep infrared. So the shape of space and time literally colors our universe.

This coloring is most spectacular in the case of the universe's first light. This light was emitted roughly 380,000 years after the Big Bang, when matter was no longer closely tied together and light could escape. It has been traveling through the universe ever since and can now be detected as microwave radiation. That signal was first detected fifty years ago—the third anniversary that makes 2015 the International Year of Light. Satellites now produce detailed maps of this primordial light, beautiful pointillist paintings cast by the universe.

In fact, light allows us to connect to the very beginning of the universe. By carefully looking at the universe's first light, we hope to detect the primordial gravitational waves or ripples out of which the universe began. A cosmological theory called inflation tells us that our universe started as a miniature speck of space that expanded to gigantic dimensions. Inflation theory is being tested right now by trying to find these swirls or fluctuations in the universe's pointillist painting. Last year, a team of researchers announced that they had detected evidence of these quantum fluctuations. While these apparent signals turned out to be galaxy dust, researchers keep looking for these signatures.

These days, Wheeler's image is more appropriate than ever. By observing light in all its manifestations we can make contact with worlds that are at the outer edge and the very beginning of our cosmos. For the first time in the history of science, we look through our biggest telescopes or biggest microscopes, peering to the end of the universe or the most inner parts of subnuclear particles, and essentially search for the same thing: What is the universe made of?

There are many beautiful ways that architects, designers, and artists shape light. But the universe might be the greatest artist, and nature is at least as imaginative as we are. ■

This article was drawn from a keynote speech that Robbert Dijkgraaf, Institute Director and Leon Levy Professor, delivered at the International Year of Light 2015 kick-off event in Amsterdam: www.ias.edu/ias-letter/2015/video/dijkgraaf-light. For more information about the International Year of Light, a global U.N. initiative, visit www.light2015.org.

How Do You Say “Bastard” in Medieval Latin?

The language of illegitimate birth reveals a rich, complex vocabulary.

BY SARA MCDOUGALL

Early this December, newspaper headlines made the sensational claim that recent DNA evidence had called into question the legitimacy of the British monarchy: scientists had identified what is known as a false-paternity event. Genetic analysis of the remains of King Richard III of England and his modern-day descendants indicated the possibility that Richard’s mother, grandmother, great-grandmother, or great-great-grandmother had a child with someone other than her husband and successfully passed that child off as her husband’s son and heir, thus corrupting the royal patriline with less-than-royal blood.

If a scholar of medieval law can be permitted to reassure a reigning monarch and her family, I would like to suggest that their dynastic claim to the throne remains safe. Medieval England by the time of Richard III had developed strict rules against allowing illegitimate children to inherit from their fathers, particularly royal or noble titles, but English law also maintained quite a generous presumption of paternity. As long as it was remotely possible that the mother’s husband could have conceived the child she presented as his, that child’s right as heir could not be challenged.

William of Normandy

That does not mean that illegitimacy raised no problems in the Middle Ages. It most certainly did. But the various ideas of illegitimate birth held by people in the Middle Ages were not necessarily the sorts of problems that we think of today. This year, I have the privilege of investigating the history of ideas of illegitimate birth, and the exclusion of bastards from royal succession, in the former institution of the great scholar of kingship Ernst Kantorowicz, and in the company of brilliant friends and colleagues who have repeatedly challenged and inspired me since my arrival in September.

As I am finding, analysis of the language of illegitimate birth reveals a rich, complex vocabulary used to indicate something less than fully legitimate birth. Terminology included both new and old words, plucked from ancient sources or transliterated from medieval vernacular languages. We find this terminology in the widest range of medieval sources, used to describe contemporaries, ancestors, and biblical and even mythological figures. Definitions vary over time and space, but also depending on the context, the kind of source, and, of course, authorial intentions.

Today we use the term *bastard* as an insult, or to describe children born outside lawful marriage. Before the thirteenth century, definitions of illegitimate birth offer more complexity and flexibility. In analyzing the language of illegitimate birth as it appears in medieval sources, we can identify three main concerns, which sometimes overlapped and were, on occasion, quite willfully conflated: social status, paternity, and marital status. Prior to the thirteenth century, the marital status of the parents had far less importance for royal succession than we might expect. Instead, attention largely focused on a child’s mother, her social status, and her sexual morals.

Consider, for example, William the Conqueror. Born in about 1028 to Robert, Duke of Normandy, and a woman most clearly not his wife, Herleva, William was nevertheless recognized by his father as his heir. Despite his youth and questionable birth, he managed to conquer and rule first Normandy and then England, and to pass his kingdom and titles onto his own heirs. This most famous of royal bastards, William I, Duke of Normandy and King of England, we find called *bastard* in medieval sources, of course, *bastardus* or *bastart*, but also called *nothus*, an ancient Greek term used in Athens to indicate illegitimate birth, birth to anyone other than two Athenian citizens. Other royal bastards might be called *mamzer*, a Hebrew term for illegitimate, or *spurius*, an ancient Latin term for a child born to illicit sex, or to an unknown father.

To my knowledge, medieval authors never called William the Conqueror *mamzer*, a term they usually reserved for the children of women described as prostitutes or promiscuous. Nor did they call him *spurius*, which they typically associated with more serious kinds of illicit or illegal sex, such as the child of a nun or priest, or the child of adultery or incest. The relationship of the bachelor Duke Robert and his concubine Herleva, if not a formal marriage, did not offend on these grounds. Nor, evidently, did anyone at the time question Herleva’s sexual honor, or, as a result, William’s paternity.

What, then, about William’s parentage did offend? Why was he called *bastard*? Writing in the twelfth century, chronicler Orderic Vitalis described this William as *nothus*. What might Orderic have meant by it? The only elaboration he offered, in a most famous passage, and the subject of much scholarly contention, suggests a concern not with William’s mother’s marital status but rather with his maternal lineage. During William’s siege of Alençon in the 1050s, as Orderic wrote, the people gathered on the battlements taunted William not about the fact that his father had not married his mother, but about his mother Herleva’s paternity, as the daughter of either a tanner or an undertaker. In other words, they objected not to his birth out of wedlock, but to his mother’s low status. This kind of illegitimate birth matches the definition of *nothus* often found in early medieval sources. Etymological texts produced in the Middle Ages, such as those of Archbishop Isidore of Seville, the Venerable Bede, and Hrabanus Maurus, all define *nothus* as a child of mixed parentage, of a noble father and an ignoble mother.

This preoccupation with mixed social status, this distaste for rulers with lower-status mothers, persists in subsequent centuries. Chroniclers of the twelfth and thirteenth centuries explicitly describe as *nothus* or *spurius*, as illegitimate sons born to lower-status mothers, not only William of Normandy (d. 1087), but also the Sicilian king Tancred of Lecce (d. 1194) and Emperor Frederick II’s son Manfred, another king of Sicily (d. 1266). We also find apologetic sources that explain that a royal child, if admittedly born outside of marriage, had a noble mother, even a most noble mother, *nobilissima*. Examples include the late-Carolingian emperor Arnulf, and, in the eleventh and twelfth centuries, the many children born to Iberian kings and their noble concubines, children who became kings and queens of Aragon, Castile, León, and Portugal.

To return to William of Normandy, our earliest sources describe William as *bastard*. The origins for this term mystify. It is evidently a medieval invention that first appears in the eleventh century, in sources written in Northern France or about people in Northern France. Some dictionaries link *bastardum* to the (medieval) Latin word *bastum*, packsaddle. From this, it is said, developed the idea that a bastard was a child born in the saddle, in French, *fils de bast*. We can understand this as indicating birth outside of a marriage bed, in transit. However, we also find the term used, like *nothus*, to indicate a union of persons born to parents of mixed social status. As one late-eleventh-century chronicler declared, the French called William *bastard* because of his mixed parentage: He bore both noble and ignoble blood, *obliquo sanguine*. Indeed, another possibility for the origins of the word *bastard* is not the *bastum*, or saddle, but *bas*, base, meaning baseborn.

William’s success, despite his birth, is not as exceptional as a good deal of prior scholarship suggests. Many other kings before and after him, and even queens, successfully inherited and reigned despite allegations of illegitimacy. We find the children of concubines, the children of annulled marriages, and even the children of monks and nuns inheriting noble and royal title, throughout the twelfth century. What scholars have often presented as evidence for a rule that excluded children born to something other than legitimate marriage is really evidence of the exercise of arbitrary power. Inheritance practices, while firmly rooted in an idea of family, operated with real fluidity and flexibility as late as the twelfth century, and even, in some places, into the thirteenth century. Fathers, for example, exercised this power in choosing one child rather than another as heir. They favored, variously, different kinds of children, including younger sons and also daughters, over their eldest sons.

In this pre-thirteenth-century world, the most intense attention was paid not to the formation of legitimate marriages but to the lineage and respectability of mothers. All this has all too often been confused with a fixed rule about legitimate marriage and lawful succession, which certainly received a good deal of lip service throughout the Middle Ages, but only had real legal meaning, legal force, beginning in the second half of the twelfth century.

Only then, particularly in the late twelfth and early thirteenth centuries, did birth outside of lawful marriage render a child illegitimate, ineligible to inherit noble or royal title. In the thirteenth century, both *bastard* and *spurius* came to signify a child born to anything other than a legitimate marriage, as defined by the canon law of the Catholic Church. This included even children born to parents both of the highest rank and married to each other, if the pope denounced the marriage as illegal. We can trace this evolution, for example, in the chronicles that describe an early twelfth-century illegal marriage made between King Philip I of France and Bertrada de Montfort, a powerful woman of high lineage and often called his queen, despite some ecclesiastical opposition to their bigamous union. In the earliest sources, we find denunciations of their marriage and cohabitation, but not of their children. We find these children called bastards, *bast*, only in a thirteenth-century French translation of an older Latin chronicle, which added this and other words to the original text. As this suggests, a discourse dominated by concerns with social status and sexual morality of the mother gave way to a discourse dominated by concerns over legitimate marriage. It is also precisely at this moment that ecclesiastical jurists, some of them popes, developed various legal mechanisms to provide, for a price, legitimacy to those whom the law classified as bastards. The new history of illegitimacy I am proposing, therefore, calls into question not only current assumptions about ideas of illegitimate birth and their implementation in practice, but also the role of the church in this history. ■

Sara McDougall, Member in the School of Historical Studies, with funding from the Andrew W. Mellon Foundation Fellowships for Assistant Professors, is investigating ideas of illegitimate birth in medieval Europe and the application of these ideas in practice between the ninth and thirteenth centuries. McDougall is Associate Professor at John Jay College of Criminal Justice and the CUNY Graduate Center.

ANDREA KANE

The IAS Questionnaire: David Spergel

The theoretical astrophysicist and Princeton University professor is well known for his work on NASA's 2001 Wilkinson Microwave Anisotropy Probe—he conceptualized the mission and deciphered the radio telescope's data to measure the age and shape of our universe and the abundance of ordinary matter, dark matter, and dark energy. A 2001 MacArthur Fellow and fall 2014 Visitor and former Member (1985–88) in the School of Natural Sciences, Spergel received the 2015 Dannie Heineman Prize for Astrophysics with Marc Kamionkowski for their investigation of the fluctuations of the cosmic microwave background, work they did when Kamionkowski was a Member (1991–95) in the School of Mathematics.

What makes you curious? I think that we are all curious. I have been fortunate to have the opportunity to have the time to explore some of the questions that have fascinated me.

Whom do you most admire and why? Galileo had the insight to point his telescope at the moon and then at Jupiter. He discovered new worlds and reshaped not only astronomy but our understanding of our place in the universe. He actively popularized his results, did both theoretical and observational work, and stood up (and suffered) for his beliefs.

Outside of your own, which field interests you most? I have always been fascinated by history and prehistory. I am fascinated by how humans have responded (or failed to respond) to challenges in the past.

How do you determine your focus? I try to identify important problems where I am likely to have a significant impact. Since there are many bright people working in astrophysics, I try to identify problems where I have a different perspective, access to new data, or a set of new tools that let me address the question in a novel way. I try to avoid areas where other scientists are doing very similar things with similar approaches.

What is the most surprising thing you've learned? Our universe is remarkably simple and remarkably strange. With only a handful of numbers (the universe's age, the density of atoms, the density of matter, the amplitude of the variations in density and its scale dependence), we can describe all of its basic properties. Yet, the universe is very strange: atoms make up only 5 percent of the density of the universe. Dark matter, most likely composed of a yet undiscovered new particle, comprises most of the mass in our galaxy. Most of the energy in the universe is in the form of dark energy, energy associated with empty space.

How do you free your thinking? I need to first get away from distractions and set aside a block of time to read and focus on a topic. I then find that I get my best insights a few days or weeks later when I let my mind wander. This can happen when I am out running, in the shower, or just relaxing. I try to avoid thinking and driving.

What question would you most like answered? Are we alone? Is Earth the only planet where life originated? Is there intelligent life elsewhere?

How has the Institute influenced your perspective? When I was a long-term Member at the IAS, John Bahcall helped shape my approach to science. John stressed the importance of addressing important questions, aiming for clarity, and staying close to the data. John contributed a great deal to the astronomy and physics community through his advocacy for science, his efforts to enable compelling projects, and through his role as a mentor. While he is no longer with us, he remains one of my role models.

Hermann Weyl, who served on the IAS Faculty from 1933 until his death in 1955, once said, "My work always tried to unite the truth with the beautiful, but when I had to choose one or the other, I usually chose the beautiful." If you had to choose between truth or beauty, which would you choose and why? Truth. The universe is the way that it is, not the way that we want it to be. Our understanding of the universe's beauty is incomplete. We often lack the deeper understanding needed to see the underlying beauty.

What is the purpose of knowledge? Knowledge both deepens our appreciation of our universe and the human condition and enables technologies that improve the quality of our lives.

What have you ignored that turned out to be crucial? I assumed that empty space was truly empty. Observations have shown that empty space is filled with dark energy. I had missed 75 percent of the universe.

ANSARI *(Continued from page 1)*

successfully completed the very highest level of study for the rank of Ayatollah, in the Shi'i clerical system. He also has studied Islamic and Western philosophy and Islamic intellectual history at universities in Tehran, Beirut, and Paris. "Hassan's command of the sources is extremely wide-ranging," says Schmidtke, "and he combines this with the very best historical-critical approach to the subjects and texts he is dealing with. He is an intimate connoisseur of manuscripts, Arabic and Persian, and the spectrum he covers is immense."

In 2009, shortly after completing his Ph.D. at the École Pratique des Hautes Études (Sorbonne) in Paris, Ansari began working as a Senior Research Associate in Schmidtke's research team at Freie Universität Berlin. Ansari, now a Member in the Institute's School of Historical Studies, has worked extensively with Schmidtke, coauthoring books, editions, and articles and co-organizing international conferences—including a conference on the city of Rayy as an intellectual center that Ansari, Schmidtke, and Professor Patricia Crone organized at the Institute in April 2014. After more than a decade of individual research and collaborative work with a number of international colleagues, Ansari says he has witnessed how his work and that of others has influenced the attitude of many scholars in Iran towards a more historical approach to Islamic theology.

A specialist of Zaydi studies, Ansari has traveled to many libraries—in Berlin, Rome (Vatican), Leiden, London, Milan, Munich, Paris, Vienna, and Yemen—to verify in depth the Zaydi and Mu'tazilite manuscripts in their collections. The available cataloguing of the manuscripts is often incomplete, riddled with mistakes, or the manuscripts have not been catalogued at all. Through the recovery and publication of these manuscripts, Schmidtke and Ansari have been working over the past six years to reconstruct lines of transmission and circles of scholars that were active at the time.

For his dissertation on the concept of religious authority in Shi'i Islam, which will be published by Brill in 2015, Ansari has used texts beginning from the eighth and ninth centuries. Through identifying quotations from earlier works, he has been reconstructing earlier layers of primary materials that are entirely lost and only preserved in these secondary sources. This has enabled him to analyze the earliest stages of the evolution of the concept of religious authority. "Many Muslim scholars take the concept of religious authority in Shi'i Islam as a static concept, which does not have any development," says Ansari. "For me, it is a historical concept, and I have studied its development through an in-depth analysis of the available sources. [My dissertation] is in many ways therefore a critique not only of the sources and the manuscripts, but also of the widely held approach of contemporary Muslim scholarship."

Today, Schmidtke, Ansari, and other Members at the Institute are working to counterbalance a trend in Western universities to focus on the exclusive study of modern Islam. "If you want to understand what happens today or since the nineteenth century, if you want to read Muhammad Abduh (1849–1905) with a critical approach, you have to understand first much of the Ash'ari tradition, which requires a thorough knowledge of Islamic theology and its primary sources," says Ansari. "You have to study the sources from the eighth and ninth centuries onwards, not only those from the eighteenth or nineteenth centuries. If you want to grasp what is happening today, you have to start with studying Ibn Taymiyya. But if you want to understand Ibn Taymiyya, you have to start with studying Ahmad ibn Hanbal and the early Hanbalite tradition."

Adds Schmidtke, "All of the thinkers and groups in modern Islam in one way or another have their roots in different strands in the Middle Ages or even before. Many scholars and pundits today take a claim at face value, when very often the claim is wrong. Look for example at ISIS. If you really know the history and the sources, you can analyze what they are doing and where they are completely wrong."

An extremely prolific writer, in Persian, Arabic, French, and increasingly in English, Ansari also regularly publishes a blog (http://ansari.kateban.com), which is extremely popular among scholars in Iran and far beyond. Since Muslim readers are one of their primary audiences, Ansari and Schmidtke both publish their works in Persian and Arabic. "This is one scholarly community," says Schmidtke. "It is one game, and we are all sitting in the same boat. In the West, because we have more possibilities than people in the Islamic world, it is our responsibility to make sure that we publish in a way that is accessible to scholars in other parts of the world, particularly the Middle East. As someone from the West working in this field, I have a responsibility to contribute something for the people whose tradition it is. There is also a very important mission for a Western audience, namely to show the intellectual richness of the Islamic world and make it available and not only to create awareness for this intellectual richness but also respect." ■ —*Kelly Devine Thomas, Senior Publications Officer, kdthomas@ias.edu*

Islamic Law and Private International Law: The Case of International Child Abduction

How can private international law reconcile differences between not only two parties, but two legal systems?

BY ANVER M. EMON

In the 1991 film *Not Without My Daughter*, Sally Field plays an American woman who has a daughter with her Iranian-born husband. When the family visits Iran, Field's character learns that her husband plans to stay in Iran with their daughter. To escape Iran with her daughter, Field's character must dupe her increasingly abusive husband, and hire a smuggler to help her and her daughter escape to Turkey. In the backdrop of the dramatic escape is an Iranian legal system premised on national laws of citizenship and Islamic legal doctrines on child custody and guardianship. That legal background informs a broad research question I am exploring while in residence at the Institute for Advanced Study concerning the relationship between Islamic law and international law. The issue of international child abduction offers a useful case study to put the stakes of this question into stark relief.

International child abduction is a particular phenomenon that implicitly reflects the complex implications of a globalized economic environment. Generally, this form of abduction occurs in the context of marital breakdown, where one parent has dual nationality. For the sake of illustration, suppose the following example. Joseph and Maria meet in college and fall in love. Joseph is originally from Pakistan, but has dual citizenship. Maria was born and raised in New Hampshire, and now lives there with Joseph and their two children. After a few years, Joseph and Maria's marriage begins to fall apart and they divorce. A court grants Maria full custody of their two children, while awarding Joseph visitation rights. Joseph is particularly upset about the custodial arrangement. One day, when the children are visiting him, Joseph goes to the airport where he and the children board an airplane to Pakistan, leaving Maria behind. Distraught, Maria contacts a lawyer to find out her legal options and how to get her children back.

A scene from Not Without My Daughter *in which a mother plots to smuggle her daughter out of Iran. Muslim-majority countries, with few exceptions, have consistently refused to ratify the international Abduction Convention of the Hague Conference, which would require them to violate their understanding of Islamic legal requirements on child custody.*

In this case, Maria will face a host of legal hurdles. Pakistan is a Muslim-majority country and its family law is informed by Islamic legal tradition. This requires us to first understand what and where Islamic law is, and why it poses an obstacle to Maria. Islamic law is a legal tradition with a long history stretching back centuries. It has been characterized by a degree of pluralism such that any particular legal issue might occasion three or more legal conclusions. This might seem strange for a religious legal tradition that seeks the presumably uniform will of God, but this diversity is hardly unusual for legal systems generally. Consider the United States federal system with its fifty states. Each state might have a different approach to a particular legal issue. And if there were no U.S. Supreme Court to resolve the difference, then those fifty different opinions would remain authoritative law within their respective jurisdictions. That sort of plurality historically has characterized Islamic law, though the conditions that delimited jurisdiction have been of a different sort.

During the period of European colonialism in the Muslim-majority world, Islamic law was replaced with a host of new laws drawn principally from the civil law tradition. Laws on property, commercial trade, and criminal law were all modeled on laws drawn from Swiss, Italian, and French inspiration. But one area of law that retained its Islamic legal influence was family law. From the colonial period, independence movements, and into the present era of modern Muslim-majority states, family law has taken the shape of a statute generally called personal status laws (Arabic: *al-ahwal al-shakhsiyya*). As a statute, it is codified in a uniform fashion; many have suggested that this new legislative form marks a fundamental departure from the early plurality that characterized Islamic law. Without taking sides on this issue, we can at the very least note that these statutes bear the imprint of an Islamic legal past. They frame issues of marriage, divorce, inheritance, and child custody in the distinct term and language of the premodern Islamic legal tradition. These statutes, therefore, represent the site where Islamic law is introduced into modern legal systems through the operation of the state and its legislative powers. Islamic law today does not exist in the air, so to speak. It is mediated through the state, taking specific shape through the complex interaction of different (and at times oppositional) state institutions.

All this insight into Islamic law, however, misses one important part of our story, namely that Maria has a custody order from a U.S. court. Doesn't that matter in this case? That will depend on whether or not Pakistan will recognize a foreign custody order. To address this question requires a discussion of private international law. Private international law, also called conflicts of law in the common law world, is a regime of law that hovers in the background in any and all legal disputes. It only comes to the aid of a judge when a case involves a foreign legal element. Foreign legal elements can arise in a wide range of cases and force a judge in one country to determine whether and to what extent the law of a different country is applicable. In other words, private international law asks the judge to consider and possibly apply the law of an "other," or rather his own legal system's "legal other." In this case, it arises the minute Maria presents the U.S. court's custody order to a Pakistani court. Will the Pakistani court yield to the determination of a U.S. court on the issue of child custody? To do so might appear as if the Pakistani judge is deferring to the U.S. court, relinquishing his judicial role, or subverting the sovereign interest of Pakistan's legal order to that of the United States. As it turns out, Pakistani case law will not support Maria's claim for her children. The foreign custody order may have no impact at all whatsoever. Rather, the foreign custody order puts into stark relief the ongoing significance of state sovereignty in the formation and imperatives of law.

In 1980, the Hague Conference issued a convention concerning these forms of international child abduction. The Hague Abduction Convention required signatories to create central authorities that would handle any claim concerning international child abduction. These central authorities are important sites for distributing information, training domestic judiciary, and facilitating the automatic return of children to what the convention called their "habitual residence." For the Hague Conference, which specializes in crafting private international law conventions, the Abduction Convention is its most successful project given the number of signatories. But despite that success, there is one abject gap in the Convention—with the exception of Morocco and Iraq, Muslim-majority countries have consistently refused to ratify the convention. They argue that to ratify the Abduction Convention would require them to violate Islamic law, given their understanding of Islamic legal requirements on child custody. As many constitutions in these states posit Islamic law as a source of the state's law, they are not constitutionally permitted to ratify the convention.

This standoff has led to a series of meetings sponsored by the Hague Conference called the Malta Process. Hosted by the government of Malta, these meetings have provided opportunities for signatory and non-signatory (mostly Muslim-majority countries) to discuss the differences between their legal systems, the conflict with the Abduction Convention, and second-best alternatives that can aid families in distress (e.g., mediation).

As much as the standoff has been posited as a contest between international law and Islamic law, I suggest that what lies at the heart of this dispute is whether and to what extent Islamic law ever developed a regime of law that recognized its legal other, and by implication its sovereign other. As I have argued elsewhere, premodern Islamic law was informed by an imperial ethic—an expansionist ethic that may have recognized a political other as a social fact but not as a legal one. The political other, in other words, did not have *de jure* status, contrary to how we today imagine sovereign states having a claim to equal status and respect as against all other states. But if the political other did not have a claim to equal status and respect, then what about its legal order? In other words, how did Islamic law view its legal other? For one legal system to recognize its legal other lies at the core of private international law. Private international law is a complex legal regime that, at its core, concerns how we legally resolve a case that not only has two parties to a conflict, but also two legal systems (and by implication the imperium of the sovereign states that issued them) present in the conflict. With two legal systems present in a given case, a judge must know how to decide which legal regime to follow. In this very technical legal dilemma lies a complex question about history, law, politics, and their implications for ongoing contests over international cooperation between sovereign states.

(Continued on page 7)

Anver M. Emon, Member in the School of Social Science, researches Islamic legal history and theory, premodern modes of governance and adjudication, and the role of Shari'a both inside and outside the Muslim world. He recently received a Canada Research Chair in Religion, Pluralism, and the Rule of Law. Emon is Professor of Law at the Faculty of Law, University of Toronto, and author of Islamic Natural Law Theories *(Oxford University Press, 2010).*

Renegade Dreams

Living through injury in Gangland Chicago

The following text is excerpted from Renegade Dreams: Living Through Injury in Gangland Chicago *(University of Chicago Press, 2014). Written by Laurence Ralph while a Member (2012–13) in the School of Social Science, the book combines African American studies, the scholarship on disability, and the field of critical medical anthropology to show how injury plays a central, though underexamined, role in the daily lives of poor urban blacks. Ralph is Assistant Professor in the departments of African and African American Studies and Anthropology at Harvard University.*

Kehinde Wiley, The Chancellor Seguier on Horseback *(2005), oil on canvas, 108 x 144 in.*

Anyone hoping to find quick references to Chicago's notorious gangs and infamous neighborhoods in this ethnography will be disappointed—as will anyone skimming the pages to find glossy snapshots of gang members. What is real about this ethnography—what hasn't been altered or rendered anonymous—are the events that I describe and the voices of my collaborators. Their voices bring to life the activities that take place on Chicago's street corners. Their voices bring dimension to people's identities and life struggles. Their voices paint a portrait of the variegated desires that stem from imagining life anew.

It's fitting in this regard that the painting that begins this book—Kehinde Wiley's work *The Chancellor Seguier on Horseback* (2005)—accurately captures the spirit of what it means to have a renegade dream. Wiley, a critically acclaimed portrait painter, is renowned for his heroic portraits that capture the status of young urban blacks in contemporary culture through reference to Old Master paintings. Adapted from a seventeenth-century Charles Le Brun painting *Chancellor Séguier at the Entry of Louis XIV into Paris in 1660*, Wiley's rendition blurs the boundaries between traditional and contemporary modes of representation by restaging the figures, and thus creating a fusion of period styles. Dressed in modern army fatigues and sweatpants, bandanas and baseball caps, T-shirts with airbrushed rappers and Air Force One sneakers, the figures in Wiley's composition are beautifully anachronistic. Yet the genius in Wiley's work is that it leads us to question: Why can't urban African Americans assume the delicate harmony and militant posture reminiscent of a Renaissance master? This book seeks to similarly restage urban blacks within societal institutions and fields of power from which they are often presumed to be excluded. Despite the statistical odds against their dreams coming to fruition in such a context, I foreground the resilience it takes for black Chicagoans to keep dreaming anyway.

There are so many kinds of dreams. But in the long tradition of African American activism, dreams have typically been linked to concrete aspirations for social reform. In his 1951 poem "Harlem," Langston Hughes, writer and social activist, famously questioned the outcome of a "dream deferred." Does such a dream dry up, fester, stink, crust and sugar over, or sag like a heavy load, he pondered. Then, foreshadowing the hundreds of race riots that would take place in the 1960s and 1970s, he ends his poem with an emphatic query: Or does it explode?

The Eastwoodians with whom I spent my days and nights over the course of three years were intimately linked to dreamers like [Barack] Obama. This was not merely because he eventually became their senator and then their president, but because he learned his first political lessons in Altgeld Gardens, an inner-city neighborhood like their own. They were also linked to dreamers like Hughes, through the tortured history that led African Americans to migrate from the South and settle in northern outposts like Harlem and Chicago; they were linked to dreamers like [Martin Luther] King through civil rights organizations, such as the Southern Christian Leadership Conference (SCLC), that met and strategized in churches and parks and run-down houses all over the West Side of Chicago. Yet their Eastwood dreams were not tied to a particular social movement like the Harlem Renaissance or the civil rights crusade. No charismatic figure vocalized their aspirations for them. Quite the opposite, in fact, particularly for the young black men at the heart of this story. Local leaders often articulated the problems of their community in terms of the "crisis of the young black male."

The people I lived with did not speak from a position of institutional authority; they knew that no one, except maybe green graduate students, cared much about their dreams. Nevertheless, Eastwoodians—young and old, male and female alike—dreamed in ways that expressed desires for a different world. Now lest I be accused of suggesting too rosy a picture, I should say that these dreams were not grandiose. These were not the genre of dreams that have been Disney-fied and squashed into the storybook realm. In fact, when I first moved into Eastwood, I did not recognize residents' struggles as dreams because they were often quite banal. Safe passage to school became something to dream for, as did a stable job and affordable, livable housing. These dreams, it is critical to note, didn't always come true: Children were gunned down on the way to school; adults searched for work to no avail; the threat of displacement haunted residents daily. In the face of these hardships, the scant resources that Eastwoodians did obtain barely scratched the surface of actual need. The brutal honesty with which they acknowledged the difficulty of real change suggested that the power of such dreams is in having them and working toward them, regardless of whether or not they come to fruition.

Another remarkable thing was this: Eastwoodians' dreams were tied to overcoming the very obstacles—mass incarceration, HIV, gun violence—that are often discussed by reporters, government officials, and scholars in terms of the ways they incapacitate people. Slowly, I began to realize, if injury immobilizes people, like that fatal bullet that fractures the spine, then dreams keep people moving in spite of paralysis. Everywhere I went—high schools, detention centers, churches, and barbershops—I witnessed people exerting tremendous effort in a desperate attempt to pursue their passions. The more time I spent with residents like Justin and Amy, the more I began to understand: In Eastwood, injury endows dreams with a renegade quality. ■

ISLAMIC LAW *(Continued from page 6)*

The example of international child abduction reveals a key concern at the heart of my research, namely a deep and abiding interest in the relationship between sovereignty and the law in a context of pluralism, whether of different and competing political orders, legal orders, or both. Indeed, in the case of Islamic law and its ongoing significance for the era of modern states, the question of sovereignty and its implication for law is paramount. Strategies for resolving this question have varied. Secularists have argued that Islamic law is an antiquated system of law that has no place in the modern state. And yet, as we have witnessed in Tunisia, Egypt, and elsewhere, Islamic law informs a larger cultural context that informs how citizens voice their aspirations in the political and legal arena. The initial gains of the Muslim Brotherhood in Egypt reflect that context, and caution us against dismissing religion generally (and Islam specifically) from the public sphere, if not for democratic reasons then at least for consequential ones. Where those voices have been curtailed, imposed upon, or simply oppressed, we see more extreme versions taking shape, whether in Egypt or elsewhere. At the time of writing, ISIS has declared an Islamic state that defies the border demarcating Syria and Iraq. Invoking premodern Islamic law as its governing legal order, ISIS has no interest in reflecting on the implications of the sovereign-state order for the logic and intelligibility of Islamic law. For them, Islamic law is outside history, already perfected, and simply requires the right conditions for its redemptive application. Those conditions, as envisioned by ISIS, pay little heed to the international state system, and thus bring to the forefront whether and to what extent Islamic law can anticipate and give space to its political and legal other.

This is not to suggest that the state and the international state system have normative content or ought to be our preferred model of political organization. It is merely to recognize that the international state system is the prevailing one today, a system that is premised on an ideal of sovereignty with implications not only for domestic law, but also for how that domestic law views the law of other states. To identify the boundaries of an Islamic legal order, the existence of other legal orders, and what happens when they "bump" into each other (both in terms of law and sovereign claims) lies at the heart of my research, given an assumption that the international state system is not dissolving any time soon. Answering those questions will not only offer insight into a specific issue like international child abduction, but arguably will help inform the ways by which those inside and outside the Muslim world reflect on sharing a future amidst different histories, political orders, and legal orders. ■

Birth of a Theorem

Six months at IAS, two-hundred-fifty pages, and a Fields Medal

Cédric Villani, Member in the School of Mathematics in the spring of 2009 and currently Professor at Université Lyon I and Director of the Institut Henri Poincaré, has called his stay at the Institute one of his most productive periods, during which more than 250 pages were written. In his Member report to then-Director Peter Goddard at the end of his stay, Villani wrote of his collaboration with Clément Mouhot from Paris, "Writing up the paper on Landau damping was one of the most intense experiences of my professional life: for three months in a row, we kept unlocking seemingly untractable obstacles on a weekly basis. Our 180-page-long paper solves a fifty-year-old open problem." A year after his IAS visit, Villani was awarded the 2010 Fields Medal, in part for the work that he did at the Institute on his proof of nonlinear Landau damping. Following are excerpts from Birth of a Theorem, *translated by Malcolm DeBevoise (Farrar, Straus, and Giroux, 2015), originally published in 2012 as* Théorème Vivant *(Éditions Grasset & Fasquelle), which describe his fervent, halting, and very human experience in trying to obtain the proof.*

Princeton, January 1, 2009

Finally, the Institute for Advanced Study—the IAS, as everyone calls it—comes into view. A little like a castle rising up in the middle of a forest. We had to go around a large golf course in order to find it. . . .

It is here that Einstein spent the last twenty years of his life. True, by the time he came to America he was no longer the dashing young man who had revolutionized physics in 1905. Nevertheless, his influence on this place was deep and long-lasting, more so even than that of John von Neumann, Kurt Gödel, Hermann Weyl, Robert Oppenheimer, Ernst Kantorowicz, or John Nash—great thinkers all, whose very names send a shiver down the spine.

Their successors include Jean Bourgain, Enrico Bombieri, Freeman Dyson, Edward Witten, Vladimir Voevodsky, and many others. The IAS, more than Harvard, Berkeley, NYU, or any other institution of higher learning, can justly claim to be the earthly temple of mathematics and theoretical physics. Paris, the world capital of mathematics, has many more mathematicians. But at the IAS one finds the distillate, the crème de la crème. Permanent membership in the IAS is perhaps the most prestigious academic post in the world!

And, of course, Princeton University is just next door, with Charles Fefferman and Andrei Okounkov and all the rest. Fields medalists are nothing out of the ordinary at Princeton—you sometimes find yourself seated next to three or four of them at lunch! To say nothing of Andrew Wiles, who never won the Fields Medal but whose popular fame outstripped that of any other mathematician when he broke the spell cast by Fermat's great enigma, which for more than three hundred years had awaited its Prince Charming. If paparazzi specialized in mathematical celebrities they'd camp outside the dining hall at the IAS and come away with a new batch of pictures every day. This is the stuff that dreams are made on. . . .

But first things first: we had to locate our apartment, our home for the next six months, and then get some sleep!

Some people might wonder what there is to do for six months in this very small town. Not me—I've got plenty to do! Above all I need to concentrate. Especially now that I can give my undivided attention to my many mathematical mistresses! [. . .]

The invitation to spend a half year in Princeton came at just the right moment. No book to finish, no administrative responsibilities, no courses to teach—I'm going to be able to do mathematics full-time. The only thing I'm required to do is show up for lectures now and then and take part in seminars on geometric analysis, the special theme this year at the IAS School of Mathematics. [. . .]

CLAIRE CALMET

Cédric Villani in the Institute woods in 2009

Right now I'm only thirty-five … but with the clarification of the eligibility rule adopted at the last International Congress of Mathematicians, from now on [Fields Medal] candidates must be under the age of forty on January 1 of the year of the congress. The moment the new rule was officially announced, I understood what it meant for me: in 2014 I will be too old by three months, so the FM will be mine in 2010—or never. The pressure is enormous!

Since then not a day has gone by without the medal trying to force its way into my mind. Each time it does, I beat it back. Political maneuvering isn't an option, one doesn't openly compete for the Fields Medal; and in any case the identity of the jurors is kept secret. To increase my chances of winning the medal, I mustn't think about it. I must think solely and exclusively about a mathematical problem that will occupy me completely, body and soul. And here at the IAS, I'm in the ideal place to concentrate, following in the footsteps of the giants who came before me.

Just think of it—I'm going to live on Von Neumann Drive!

Princeton, January 17, 2009

Saturday evening, dinner together at home.

The whole day was taken up with a trip organized by the Institute for visiting members. A trip to the holiest of shrines for anyone who's enthralled by the story of life: the American Museum of Natural History in New York.

I recall very well my first visit to this museum, almost exactly ten years ago. The excitement of seeing some of the most famous fossils in the world, fossils whose pictures are found in the guides and dictionaries of dinosaurs that I devoured as a teenager, was indescribable.

Today I went back ten years into the past and left my mathematical cares behind for a few hours. Over dinner, however, they caught up with me.

Claire was rather taken aback, seeing my face contorted by tics and twitches.

The proof of Landau damping still hasn't come together. My mind was churning.

What do you have to do, for God's sake, what do you have to do to get a decay through transfer of regularity with respect to position when the velocities have been composed … this composition is what introduces a dependence with respect to velocity—but I don't want any velocities!

What a mess.

I scarcely bothered to make conversation, responding in as few words as possible, otherwise by grunts.

"Was it ever cold today! We could have gone sledding. . . . Did you happen to notice the color of the flag at the pond this morning?"

"Hmmm. Red. I think."

Red flag: even if the pond looks frozen, walking on it is prohibited, it's too dangerous. White flag: go ahead, guys, the water's frozen solid, jump and shout, dance on the ice if you like.

And to think that I accepted an invitation to present my results at a statistical physics seminar at Rutgers on January 15! *How* could I have accepted when the proof wasn't complete? What am I going to tell them?

Well, when I got here at the very beginning of the month, I was completely sure I could finish the project in two weeks—max! Fortunately the talk got pushed back by another two weeks! But even with this reprieve, am I going to be ready?? January 29 isn't very far away!! I never thought it would be so hard. No way I could have foreseen the obstacles that lay ahead!

The velocities are the problem, the velocities! When there isn't any dependence with respect to velocity, you can separate the variables by means of a Fourier transform, but when you've got velocities, what can you do? In a nonlinear equation, velocities are obligatory—there's no way I can avoid dealing with them!

"Are you all right? Really, there's no point worrying yourself sick! Relax, take it easy."

"Can't."

"You really seem obsessed."

"Look, I'm on a mission. It's called nonlinear Landau damping."

"I thought you were supposed to be working on the Boltzmann equation. That was your big project, wasn't it? You don't want to lose sight of what you came here to do, do you?"

"Can't be helped. Right now it's Landau damping."

But Landau damping goes on playing the cold, unattainable beauty. I can't get next to her.

. . . Still, there's that little calculation I did on getting home from the museum—doesn't that give some reason for hope? But man, is it ever complicated! I added two more parameters to the norm. Our norms used to have five regularity indices, which already was the world record—now they're going to have seven! But so what, applying the two indices to a function that doesn't depend on velocity leaves you with the same norm as before, there's no inconsistency. . . . I've got to check the calculation carefully. But if I try to do it right now, it's going to turn out wrong, so let's wait until tomorrow! I'm going to have to do the whole damn thing over again, this time with norms that have got seven indices. Good Lord.

Seeing how glum I looked, Claire felt sorry for me. Or at least felt she had to do something to cheer me up.

(Continued on page 9)

"Look, tomorrow's Sunday. You can spend the day at the office if you like; I'll take care of the little lambkins."

At that moment, nothing in the world could have pleased me more.

Princeton, January 21, 2009

Thanks to the rabbit I pulled out of my hat on my returning from the museum the other evening, I've been able to get back on track. But today I'm filled with a strange mixture of optimism and dread. Got around one major roadblock: made a few explicit calculations and eventually figured out how to manage a term that had gotten too big—that much gives me hope. At the same time, the complexity of the mathematical landscape that's now opened up makes my head spin if I think about it for more than a few moments.

Could it really be that Vlasov's splendid equation, which I thought I was beginning to get a handle on, operates only by fits and starts? On paper, at least, it looks as though sometimes the response to external perturbations suddenly occurs very, very quickly. I've never heard of such a thing; it's not in any of the articles and books that I've read. But in any case we're making progress.

Princeton, February 27, 2009

A bit of a party atmosphere at the Institute today now that the five-day workshop on geometric partial differential equations is coming to an end. Very fine casting, with many stars—all the invited speakers agreed to participate.

In the seminar room I found a place to stand all the way at the back, behind a large table. Sometimes an audiovisual control board is set up on it, but not today, so I could spread out my notes on top. There's no better place to be. I was lucky to get there before Peter Sarnak, a permanent professor at the Institute who likes it as much as I do. You can always be sure of staying awake, for one thing. If you're sitting in a chair you're more likely to drift off—and you've also got to settle for writing on a small fold-down tablet.

I like to be able to pace back and forth in my stocking feet when I'm listening to a lecture, ideal for stimulating thought.

At the break I rushed outside without bothering to put my shoes back on and ran upstairs to my office. Quick phone call to Clément.

"Clément, did you see my message from yesterday with the new file?"

"You mean the new scheme you got by writing down the characteristic equations? Yeah, I looked at it and I began to do the calculations. Looks like a bear to me."

Monster, beast, bear—these words occur over and over again in our conversations. . . .

"I have a feeling we're going to run into problems with convergence," Clément continued. "I'm also worried about Newton's scheme and the linearization error terms. There's another technical detail, too—you're always going to have scattering from the previous step, and it won't be trivial!"

I was a bit annoyed that my brilliant idea hadn't convinced him.

"Well, we'll see. If it doesn't work, too bad, we'll stick with the present scheme."

"It's pretty wild—we've got more than a hundred pages of proofs by this point and we're still not done yet!! Do you really think we'll ever finish?"

"Patience, patience. We're almost there. . . ."

The intermission in the seminar room was over. I hurried back downstairs to hear the concluding talks.

Princeton, March 1, 2009

I read the message that had just appeared on my computer screen, and then read it again. Couldn't believe my eyes.

Clément's come up with a new plan? He wants to give up on regularization? Wants to forget about making up for the loss of regularity encoded in the time interval?

Where did all this come from? For several months now we've been trying to make a Newton scheme work with regularization, as in Nash–Moser—and now Clément is telling me that we need to do a Newton scheme without regularization? And that we've got to estimate along the trajectories, while preserving the initial time and the final time, with *two* different times??

Well, maybe he's right, who knows? Cédric, you've got to start paying attention, the young guys are brilliant. If you don't watch out, they're going to leave you in the dust!

Okay, there's nothing you can do about it, the next generation always ends up winning . . . but . . . *already*?

Save the sniveling for later. First thing, you've got to try to understand what he's getting at. What does this whole business of estimating really amount to, when you get right down to it? Why should it be necessary to preserve the memory of the initial time?

In the end, Clément and I will be able to share the credit for the major innovations of our work more or less equally: I came up with the norms, the deflection estimates, the decay in large time, and the echoes; he came up with the time cheating, the stratification of errors, the dual time estimates, and now the idea of dispensing with regularization. And then there's the idea of gliding norms, a product of one of our joint working sessions; not really sure whose idea that was. To say nothing, of course, of hundreds of little tricks . . . [. . .]

If Clément is right, the last great conceptual obstacle has just been overcome. On this first day of March our undertaking has entered into a new phase, less fun, but also more secure. The overall plan is in place, the period of free-ranging, open-ended exploration is over. Now we've got to consolidate, reinforce, verify, verify, verify. . . . The moment has come for us to deploy the full firepower of our analytical skills!

Tomorrow I'm taking care of the kids; there's no school on account of the snowstorm. But come Tuesday, the final push begins. One way or another the Problem simply has *got* to be tamed, even if it means going without sleep. I'm going to take Landau with me everywhere—in the woods, on the beach, even to bed. Time now for *him* to watch out!

Princeton, night of April 8–9, 2009

Version 55. The tedious process of rereading and fine-tuning. Then, suddenly, a new hole opens up.

Hopping mad, I've just about had it.

Had it up to here *with this whole business! Before it was the nonlinear part. Now it's the linear part that seemed to be under control and then came apart at the seams!*

We've already announced our result more or less everywhere: last week I gave a presentation in New York, tomorrow Clément's doing the same in Nice. There's no excuse for the slightest error at this point—the thing has to be completely correct!!

But there's no getting around it, there *is* a problem. Somehow this damn Theorem 7.4 has got to be fixed. . . .

The children are asleep, Claire's away again. Working in front of the big picture window, looking out into the dark night. The hours go by. Sitting on the sofa, lying on the sofa, kneeling in front of the sofa, I turn my bag of tricks inside out, scribbling away, page after page. To no avail.

I go to bed at four o'clock in the morning in a state close to despair.

Princeton, June 26, 2009

My last day in Princeton. Rain, nothing but rain the last few weeks—so much, in fact, it was almost comical. At night the fireflies transform the oaks and red maples into Christmas trees, romantic, impossibly tall, decorated with innumerable blinking lights. Enormous mushrooms, a small furtive rabbit, the fleeting silhouette of a fox in the night, the startling noises of stray rutting deer . . .

In the meantime a lot has happened on the Landau damping front! We were finally able to get the proof to hang together, went through the whole thing one last time to be sure. What a wonderful feeling, finally to post our article online! As it turned out, it was in fact possible to control the zero mode. And Clément discovered that we could completely do without the double time-shift, the trick I came up with on my return from the Museum of Natural History back in January. But since we didn't have the courage to go over the whole thing *yet again*, and since we figured it might come in handy dealing with other problems, we left it where it was. It's not in the way, not interfering with anything. We can always simplify later if we have to.

By this point I've given quite a few talks about our work. Each time I was able to improve both the results and the exposition, so the proof is now in very good shape. There may still be a bug somewhere, of course. For the moment, however, all the pieces fit together so well that if an error is discovered, I'm confident we'll be able to fix it. [. . .]

The state of mathematical grace in which I had been living almost from the beginning of my stay in Princeton lasted until the very end. Once the Landau damping problem was solved I immediately went back to my other major project, the collaboration with Ludovic and Alessio. Here again, just when the proof seemed to be in jeopardy, we were able to overcome all the obstacles facing us and everything began to click, as if by magic. Our good fortune included one true miracle, by the way, an enormous calculation in which fifteen terms recombined to constitute a perfect square—an outcome as unhoped for as it was unexpected, since ultimately what we succeeded in demonstrating was the opposite of what we had set out to demonstrate!

With regard to Landau damping, it must be admitted that Clément and I didn't manage to solve quite everything. For electrostatic and gravitational interactions, the most interesting cases, we were able to show that damping occurs on a gigantic time scale, but not an infinitely long one. And since we were stymied on this point, we were also stymied on regularity—we couldn't find a way to get out from the analytic framework. Very often at the end of my talks somebody would ask one of these two questions: *In the case of Coulomb or Newton interaction, does one also have damping in infinite time? Can one do without the analyticity assumption?* In either case my response was the same, that I couldn't say anything without consulting my lawyer first. Honestly, I don't know whether there's a profound mystery here, or whether we simply weren't clever enough to work out the answer. [. . .] ■

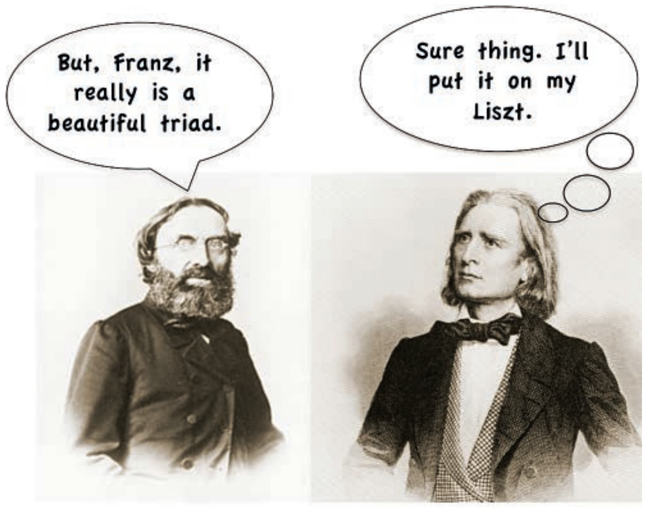
Recommended Event: Cédric Villani will give a public lecture at the Institute on Tuesday, April 14. For more information, visit www.ias.edu/villani-2015.

Music Theory's Monstrous Chord

How a lone theorist's pursuit of symmetry shaped music history

BY SUZANNAH CLARK

On the second Sunday after Trinity in 1724, the congregation at the Thomaskirche in Leipzig heard Johann Sebastian Bach's new cantata that began with the words *Ach Gott*. Bach set the word *Gott* to the most dissonant triad known at the time: the augmented triad. Bach's own son, Carl Philipp Emanuel Bach, wrote in the second volume of his treatise of 1762 that the offending augmented fifth of this harmony requires careful preparation. His father did not prepare it at all. Acclimatized as we are today to all kinds of dissonances, this harmony might pass the modern listener by. But it would have disconcerted the ears of the eighteenth-century congregation, giving them a God-fearing shudder, while setting the scene for the biblical message of the day. Bach, after all, was setting the tune and words, *Ach Gott, vom Himmel sieh darein*, that Martin Luther had penned exactly two hundred years earlier, in 1524. Based on Psalm 12, Luther tells of a perilous world filled with those who shun God.



The augmented triad has long been a headache for music theorists, only partially on the basis of its harsh sound. Mostly they are perturbed by its construction and their inability to pinpoint a convincing origin for it. It would be no exaggeration to say that, just two years before Bach composed his cantata, the harmonic theory of Jean-Philippe Rameau, a towering figure in the history of music theory, brought about a paradigm shift in how chords were categorized and understood to have been constructed. Although much of Rameau's theory still holds sway today, a now defunct aspect of his *Traité de l'harmonie* led him to deem the augmented triad "worthless." It belonged to the rubbish heap of potential chords because it did not contain the right kind of fifth, and therefore it must be an incomplete chord. According to Rameau's newly minted theory, all valid, complete chords must contain a perfect fifth; the augmented triad gets its name from the fact that its fifth is "augmented" (it is a semitone larger than the perfect fifth).

Rameau salvaged the triad by adding two more notes to it, turning it into a five-note harmony. Now completed to his satisfaction, the sonority corresponded to one he had undoubtedly heard before, for in this guise it is prevalent in the music of French composers in the generation before Bach: Couperin and Charpentier were especially keen on it. In this context, Bach's use of the sonority—without the camouflage of the extra two tones—is all the more striking.

It was not until 1853 that the augmented triad—as a three-note entity—would come to be treasured by music theorists for its construction. Thanks to the invention of equal temperament (our modern tuning system), the theorist Carl Friedrich Weitzmann was able to see in this triad a beautifully symmetrical construction. It divides the octave into three equal segments and has the rare property of inverting into itself. In his view, it had been unfairly maligned by his closest predecessors as "monstrous" and as a chord that "screams its shrill sound at us."

In part, Weitzmann's attention was drawn to the triad due to a theoretical blunder that took place at the turn of the nineteenth century, a blunder that had everything to do with a misstep in theorists' quest for another kind of symmetry. One of the primary ambitions since the mid-eighteenth century had been to explain the two modes of the tonal system—major and minor—through an identical set of principles. I shall therefore now turn to a brief history of this quest, illustrating how it shaped the design of the fundamentals of music theory. We shall see how this blunder came about in 1817 and how it gave the augmented triad an unexpected new lease of life.

When the major and minor modes emerged from the church modes at the dawn of modern tonality (arguably ca. 1600), the major mode quickly developed into a stable shape. It was represented by a single scale and therefore the identity of its harmonies, which are made up of various combinations of notes from the scale, was crystal clear. By contrast, the minor mode was unstable: there are no fewer than three versions of the minor scale, known as the "natural," "harmonic," and "melodic" scales, each of which suggests that a different set of harmonies are intrinsic—or "diatonic" to use the technical term—to the minor mode. While the first five notes are identical in all three versions of the minor scale, the next two notes proceed in various patterns. In the case of the "melodic" minor scale, its pattern even differs when the notes are played on the way up versus on the way down.

Suzannah Clark, Edward T. Cone Member in Music Studies in the School of Historical Studies, is tracing why music theorists sought to explain foundational concepts of tonality using symmetrical principles and why their ambition never worked out, leaving inexplicable "quirks" in their theories. Clark is Professor of Music Theory at Harvard University.

There thus arose a fundamental inequality between the two modes: while major had one scale, minor had three; while major had few diatonic harmonies, minor had many. Instead of relishing the differences between the modes (as composers seemed to do), theorists tried to iron them out, in what turned out to be an ever-elusive quest for symmetry.

The habit amongst theorists was generally to acknowledge all three versions of minor, but to pick one as foundational in an attempt to replicate the basic condition of the major mode. The choice is mostly determined by what century a theorist was writing in. The eighteenth century witnessed a preference for the natural minor. It is the only version of minor not to contain the augmented triad, which meant theorists could easily navigate around it. Most simply repeated Rameau's view of it. At the turn of the nineteenth century, theorists switched to the harmonic minor, and for the first time had to confront the possibility that the augmented triad might be a fundamental harmony.

A number of cardinal theoretical ideas—still cherished today—would not have been possible without the eighteenth-century preference for the natural minor. For instance, the notion developed that all twenty-four major and minor keys would be organized into pairs of twelve keys that share the same key signature. This idea also lies at the heart of the development of music theory's most iconic diagram, the circle of fifths—a diagram still used today to teach key signatures. The theory of key signatures could so easily have gone differently. Take, for example, C major, which is made up of the pitches C D E F G A B C. Its relative minor pair is A minor, which in its natural minor incarnation contains the same pitches but starting from a different point: A B C D E F G A. These two therefore share the same key signature of no sharps or flats. By contrast, the pitches of A harmonic minor are: A B C D E F G♯ A, which would have necessitated the signature of one sharp, G♯. This signature is certainly theoretically possible—and was mooted in the nineteenth century—but it never caught on.

Although the natural minor clearly led to important theoretical ideas, it lacked the capacity to reflect musical practice in one crucial respect. In theory, its three primary harmonies are all minor; in composition, one of those primary harmonies—known as the dominant—is invariably major. This dominant is especially critical to cadences, which are the musical equivalent to commas and full stops that punctuate sentences. To obtain this all-important harmony, eighteenth-century theorists either cherry-picked it from the harmonic minor scale or, more commonly, they argued that it was borrowed from the major mode.

At the beginning of the nineteenth century, theorists began to argue that this dominant major harmony was so prevalent in minor-mode music that it needed to be shown to be diatonic, rather than borrowed from elsewhere. They therefore turned to the harmonic minor as their new foundational scale. While gaining the dominant was a triumph, lurking on the third degree of the scale was none other than the augmented triad. With the precedent set in the eighteenth century that fundamental harmonies are defined as those harmonies that are made up of notes from the scale, the augmented triad seemed poised to become a fundamental harmony.

Numerous early nineteenth-century theorists welcomed the new role for the harmonic minor scale, but few were ready to embrace the augmented triad. In 1817, Gottfried Weber, a lawyer by trade and an avid musician, critic, and theorist in his spare time, came up with an astonishing solution, a solution that would dominate the theoretical landscape for over half a century and change the way that hitherto staple harmonies of the tonal system were heard. Instead of presenting the augmented triad in his showcase diagram of the fundamental chords, Weber put a rest in its place. Perceiving the chord as "monstrous," he not only eliminated it from view, but the musical rest—the notational symbol for silence—ensured that nothing reached the ears either. This absence was no accident, for throughout Weber's multi-volumed treatise published over five years, there are numerous other blanks in dozens of other tables and chasms in his theoretical examples of chord progressions wherever this "monstrous" chord ought otherwise to have appeared.

Weber is especially famous for inviting composers to open their minds to all possible combinations of fundamental chords in all twenty-four keys. He calculated a staggering 6,888 possibilities, but the real surprise—at least for me, as a historian of music theory—is that, if the rest (and his three other equally curious missing chords) were filled in, the number would have been 9,380. To compensate for these absences, he had to develop a new—and strange—theory of modulation and harmonic perception. Weber thus had plenty of opportunity to witness the limiting effects of his rest—indeed his blunder. Yet he tenaciously held to his theory.

(Continued on page 11)

Panofsky's Suppressed Treatise on Michelangelo

Situating Michelangelo within a long philosophical and religious tradition, extraneous to nation or race

BY GERDA PANOFSKY

In the Spring 2013 *Institute Letter*, Uta Nitschke-Joseph wrote "A Fortuitous Discovery: An Early Manuscript by Erwin Panofsky Reappears in Munich," in which she reconstructed the convoluted fate of the lost, and in 2012 re-found, Habilitation thesis of Erwin Panofsky (1892–1968), one of the founding members of the School of Historical Studies and an eminent art historian of the twentieth century. After two years of transcribing, editing, and proofreading the manuscript, I am happy to report that the volume has been published by De Gruyter in October 2014. The release coincides with the centennial of Panofsky's doctoral dissertation at Albert-Ludwigs-Universität Freiburg in 1914, printed by a predecessor of the same publishing house, and the eightieth anniversary of his forced emigration from Germany in 1934, after which point in time there had been no trace of the some 340 pages anymore (presumably left behind in the off-limits university office). Moreover, 2014 happened to be the 450th anniversary of Michelangelo's death. An English translation of the book is being prepared by Princeton University Press.

The unfinished text of 1920, modified and enlarged over the following years, is a stylistic analysis of Michelangelo's (1475–1564) paintings and sculptures, first in comparison with those of his peer Raphael, who, however, was not a sculptor and whom Michelangelo survived by more than four decades, thereby reaching into the periods of the so-called Mannerism and the Early Baroque, which Raphael did not live to see. According to Panofsky, Michelangelo found himself in an artistic conflict between cubic confinement and the dynamic movements of his figures. As his stylistic principles were idiosyncratic and outside the contemporary trends, his œuvre has to be defined against the art of Egypt, antiquity, the Middle Ages, and the Renaissance, as well as the later Baroque. Universal or macro history characterizes also other publications by Panofsky from the 1920s. It is important to note that he never doubted the continuity of Western civilization. While Oswald Spengler, in *Der Untergang des Abendlandes (Decline of the West)* of 1918, at the end of World War I, proclaimed the downfall of the Occident, Panofsky after his demobilization from the military service in January 1919 devoted himself to the epoch of the Renaissance (the "rebirth" of antiquity), from which lastly Michelangelo could not be extracted.

A hint that this was not an escape from the grim reality, but a conscious protest against the rising endeavors to monopolize Michelangelo, the greatest Italian artist, for the nationalistic and increasingly racist art-historical writing in Germany, is given by the motto of the thesis, which is a quotation from Gotthold Ephraim Lessing (1729–81), the poet of "Nathan the Wise" and one of the foremost representatives of the Enlightenment. In 1920, the same year of his Habilitation at Universität Hamburg, Panofsky conceived also his lecture on "Rembrandt and the Jews" to be presented at the Hochschule für die Wissenschaft des Judentums in Berlin. How appropriate its timing was became soon evident from the fact that in 1922 the notorious study by Hans Günther, *Rassenkunde des deutschen Volkes (Racial Science of the German People)*, would appear in Munich. Perhaps it was not a coincidence that around 1923, as can be proven, Panofsky thoroughly revised his final chapter on Michelangelo with the heading "The Concept of Man with Regard to His Psychic Structure," in which he derived the tensions of modern man between the spiritual and the animalistic—and ultimately Michelangelo's split principles—from the teachings of ancient philosophers such as Aristotle and medieval theologians such as Thomas of Aquinas. Michelangelo's artistic struggles would thus be predestined by a long philosophical and religious tradition, extraneous to nation or race. When Michelangelo toward the end of his life carved the *Pietà Rondanini*, which seems dematerialized, or when he then wrote poems, which renounced the passions and submitted his soul to the love of God, Panofsky's interpretation thereof appears influenced by the *Ethics* of the Jewish philosopher Baruch Spinoza (1632–77), another favorite author of his beside Lessing. The book of the twenty-eight-year-old scholar is no less based on his humanistic education than rooted in his Jewish upbringing.

Recommended Reading:
"A Fortuitous Discovery: An Early Manuscript by Erwin Panofsky Reappears in Munich" by Uta Nitschke-Joseph: www.ias.edu/nitschke-joseph-manuscript.

In determining the *Gestaltungsprincipien Michelangelos*, Panofsky also liberated them from chauvinistic bias. If after his emigration to the United States he refused to return to his beloved specialty—aside from having lost his manuscript, on which he had labored for so many years—it might have had to do with his disgust of the politicizing of the subject. In one last attempt to stem the tide, he resorted to the Warburgian method in demonstrating the Neoplatonic influence on Michelangelo (in the Mary Flexner Lectures delivered at Bryn Mawr College in 1937). Once again, he summarized how "in Michelangelo's last works the dualism between the Christian and the classical was solved. But it was a solution by way of surrender." The final sentence of the last of the Bryn Mawr lectures, in which Panofsky deplores "a gradual disintegration both of Christian faith and classical humanity, the results of which are very much in evidence in the world of today," throws light on the actuality of the *Gestaltungsprincipien Michelangelos* written in Germany a decade and a half earlier.

While we might never fully know the inner reasons for Panofsky's abandonment of his Michelangelo research, the neat break after the emigration in 1934 occurred hardly by chance and surely was related to the ostensible victory of the bigoted Michelangelo cult in Germany. Conversely, the hiding of the manuscript by his former student Ludwig H. Heydenreich (1903–78), among whose Nachlass it happened to be unearthed, must have had to do with repressed feelings of guilt by someone, who while never joining the Party of the Nazis, nevertheless had pursued his career under their regime.

Erwin Panofsky's book as it is finally published (including the complete facsimile of the original) remains important for the study of Renaissance art and has not lost its relevance; on the contrary, it retrospectively reveals even more its significance for our field than could have been appreciated in the 1920s. It offers not only new insights into Michelangelo's receptiveness to Greek masterpieces such as the *Laokoön* or the *Torso Belvedere*, his emphasis on the one-sided view of statues, his predilection for seated figures, his aversion to portraiture, and much more, but also in over five hundred footnotes evaluates the ongoing scholarly Michelangelo debate of his time. As indicated above, the book concludes with a reading of Michelangelo's poetry. ■

Gerda Panofsky, Professor Emerita of Art History at Temple University, was a former Research Associate (1965–66) in the School of Historical Studies. Her husband, Erwin Panofsky, was a Professor in the School of Historical Studies from 1935–68, and she is the sole editor of his rediscovered Habilitationsschrift on Michelangelo.

MUSIC THEORY *(Continued from page 10)*

Did anyone else hear music this way? The short answer is yes. A litany of theorists followed suit and at least one aesthetician defined "the beautiful" in music through Weber. Fascinating as it would be to trace that history, my story resumes with Weitzmann, who rescued the augmented triad in 1853.

Weitzmann wrote a whole treatise on the triad, observing that it "has been previously considered by all theorists and practical musicians to be a sinister guest, whom they believed they must get rid of as soon as possible. Its questionable heritage aroused suspicion; its harsh manner and apparent awkwardness were not suited to winning it friends. . . . [It deserves] to be granted a permanent place in the kingdom of tones."

He found a new origin for it. If the major and minor triads are inverted around an axis of symmetry, say the pitch E, then the augmented triad can be shown to lie at the center of the tonal system: A C E G# B. Clever, but dubious. Nonetheless, Weitzmann's lasting contribution is that he recognized the triad's symmetrical properties and its capacity to elicit new tonal adventures. He came up with thirty-two ways to resolve the chord, whereas his predecessors had only ever mustered up one or two. He sent his treatise to his friend Franz Liszt, who promptly made use of its principles, and his music became littered with augmented triads in guises first explained theoretically by Weitzmann.

Until recently, Weitzmann was all but forgotten. Yet clearly his impact on music was profound and unprecedented: the old adage is that theory lags behind practice. However, in his day, he was also lauded for his ability to explain practice. Weitzmann responded to a competition for the best explanation of the compositional techniques of the so-called New German School, of which Liszt and Wagner were considered members. To be sure, Weitzmann's resultant, expanded treatise, *Harmoniesystem* (1860), is a good read, but it is perhaps no surprise that he won, since it was his theory that had infused fresh creative energy into the harmonic language of the New German School in the first place. A sneaky win.

But Weitzmann's impact did not end there. The kind of theoretical appreciation for the symmetry of the augmented triad spawned a kind of theoretical thinking that lies at the heart of a branch of mathematical music theory that is all the rage in academia today. ■

Memories of the Institute for Advanced Study

Visits with Einstein and the Discovery of Color

BY OSCAR "WALLY" GREENBERG

The Institute played an important role in my life on two occasions—as a graduate student at Princeton University in the 1950s, and as a visiting Member in 1964.

1952–54: Five encounters with Einstein

As a graduate student in Princeton from 1952 to 1956, I went to the Institute to attend seminars. I visited Einstein in his office and in his home, and introduced Einstein at the last seminar he gave.

I saw Einstein three times to learn about the theory with a non-symmetric metric he was considering in order to unify gravity and electromagnetism. Meeting with Einstein was exhilarating and I felt awed in his presence; however, the meetings were not helpful for my understanding of his unified theory. If something was not clear, I was too much in awe of Einstein to press him for further explanation. As an example of my diffidence, one visit to Einstein was just before lunch. As it was winter, Einstein started to put on his heavy grey cloth coat before going out to walk home. I had an impulse to help him on with his coat, but did not because I felt this would be too intimate. I found it more helpful to meet with Bruria Kaufmann, Einstein's scientific assistant; I felt at ease with her and was able to press her when I did not understand her explanations.

Years later, I heard that Robert Oppenheimer had told postdocs at the Institute not to bother Einstein. I don't think that was doing Einstein a favor, because Oppenheimer's admonition isolated Einstein even more than he was already because of his refusal to accept quantum mechanics.

My most memorable meeting with Einstein was in 1953. John Wheeler took his general relativity class to ask questions of Einstein and to have tea with him in his home on Mercer Street. We walked across Princeton as if we were going to a museum. We asked Einstein questions ranging from Mach's principle and the expanding universe to his attitude toward quantum theory. He appeared very humble. He took our questions seriously and answered our questions fully, including a question about the future of his house. He answered straightforwardly: "This house will never become a place of pilgrimage where people come to see the bones of the saint." I felt that Einstein had not accomplished all he had hoped to do and was ready to pass the torch to us. When Wheeler asked Einstein what advice he would give to these young men who aspire to become physicists, Einstein simply shrugged his shoulders and said, "Who am I to say." The poem "Mercer Street" recalls this visit to Einstein in his home.

Oscar "Wally" Greenberg (owgreen@umd.edu) is a physicist and Professor at the University of Maryland, College Park. In 1964, while at the Institute as a Member in the School of Natural Sciences, Greenberg posited the existence of a hidden, three-valued charge, called color charge, of subatomic particles, "quarks," the same year that quarks were posited as constituents of hadrons by Murray Gell-Mann and, independently, by George Zweig. To read more about the origin of Greenberg's discovery of color in quarks, see his feature in Physics Today *(January 2015): www.ias.edu/ias-letter/2015/article/greenberg-color.*

Mercer Street

A spring afternoon
A line of nine walk though the town
A musty house, the shutters drawn
A sage lives within

His key turned the lock
For twenty years to unify
Electric field, magnetic field
Space-tine matter, too

A calm beyond time
A humble man received his guests
To talk, to feel the breath of youth
To hand them the key

The day turned to dusk
The parting time. Advice was sought
For these young men who start the path
He lost long ago

He shrugged. Scratched his head,
Discomforted, at sea, he sent
Them out with "Who am I to say?"
Cool air cleared their heads

The last time I saw Einstein was on April 14, 1954, when I introduced him at the last seminar he gave. We kept his planned talk quiet so the whole town of Princeton would not show up. Einstein talked about the difficulty of combining quantum mechanics with special relativity. I don't remember my introduction, except that it was brief. If ever there was a person who needed no introduction it was Einstein.

1964: The Institute's atmosphere for discovering color in quarks

Important developments in particle physics took place in 1964. Spontaneously broken symmetry pioneered by Yoichiro Nambu, and independently developed by Robert Brout and François Englert, and by Peter Higgs, as well as by Gerald Guralnik, Richard Hagen, and Tom Kibble, was proposed in 1964. This work led to what is now called the Higgs mechanism as a solution to a number of difficulties with the quantum field theory of elementary particles. The quark model and color also were introduced in that year. Indeed, the framework in which we think about particle physics was established in 1964. This recollection focuses on the quark model and color.

The increasing number of apparently elementary particles, first found in cosmic rays, and then produced in accelerators, required a framework to bring order to the new data. Murray Gell-Mann's eightfold way, and similar work by Yuval Ne'eman, grouped the new particles in sets of eight (octets) and ten (decuplets) connected with the symmetry group, $SU(3)_{flavor}$, that preserves the length of three-dimensional complex vectors.

Initially, the fundamental "flavor" triplet of $SU(3)$ was not used to describe these particles. In 1964, George Zweig and Gell-Mann independently introduced this triplet as fundamental entities underlying the observed particles, and they called the fundamental triplet "aces" and "quarks" respectively. Zweig thought of his aces as concrete particles; by contrast, Gell-Mann initially thought of his quarks as mathematical objects to be used to construct the octets and decuplets. Their quark model placed the mesons in quark-antiquark states and the baryons in 3-quark states. They chose charges $2/3, -1/3, -1/3$ for the flavor triplet in order to produce the requisite integer charges for the mesons and baryons. They chose spin-1/2 for the quarks in order to have the observed spins for the baryons. The low-lying mesons fit into an octet of pseudoscalar mesons (spin-zero particles that change sign under space inversion) and an octet plus a singlet of vector mesons (spin-one particles). Of more interest for what follows, the low-lying baryons were assigned to an octet of spin-1/2 particles, including the proton and neutron, and a decuplet of spin-3/2 particles. This decuplet included the Δ^{++} containing 3 up quarks with parallel spins. There was no reason, aside from the charge and spin assignments, for the quark and antiquark compositions of the baryons and mesons. This was the situation in September 1964, when I arrived at the Institute for Advanced Study.

The atmosphere at the Institute in 1964

My apartment and my office were both ready: I could hit the road running and start work immediately. Evenings I would join friends and play ping pong at a table in the Institute basement. I had a vicious topspin left-hand slam and discharged a lot of aggression at the ping-pong table.

People at the Institute were very excited about a paper by Feza Gürsey and Luigi Radicati.[1] They unified the spin-1/2 positive parity nucleon octet and the spin-3/2 decuplet in the 56-dimensional representation of the larger group, $SU(6)$, (the group that contains the product of the two possibilities of spin up and spin down times the three "flavors" colloquially called "up," "down," and "strange"). Benjamin W. Lee, who was also at the Institute, gave me a preprint of the paper he had just finished with Mirza A. Baqi Beg and Abraham Pais, both of whom had just moved to the Rockefeller Institute (shortly to be renamed "University"). In their paper, they calculated the ratio of the magnetic moments of the proton and neutron in the 56-dimensional representation of $SU(6)$ with the result $-3/2$, which agreed with experiment to within 3 percent.[2] From our present perspective, this result was too good, since quark-antiquark pairs and gluons, among other things, such as relativity, were ignored. Nonetheless, this result, together with the supermultiplet 56-dimensional representation of $SU(6)$, convinced me that quarks were real and should be taken seriously as constituents of hadrons. I became an enthusiastic believer in quarks.

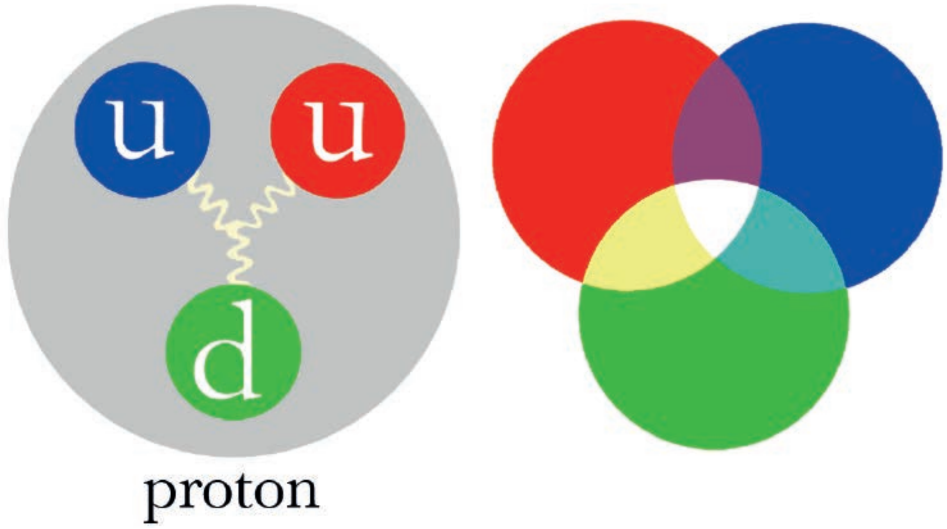
The quark model required the quarks to have spin-1/2. The spin-statistics theorem implied that

(Continued on page 13)

they are fermions and must be in antisymmetric states under permutations. Surprisingly, the $SU(\mathbf{6})$ model of Gürsey and Radicati placed the three quarks in the symmetric three-particle representation of the permutation group, the 56-dimensional representation of $SU(\mathbf{6})$. *This presented the paradox that the quarks seemed to behave as bosons instead as fermions as they should have.*

With the background of the work on parastatistics I had done with Albert Messiah,[3] I realized that this paradox would be resolved if the quarks obeyed parafermi statistics of order-3. I had arrived at the Institute knowing the solution to the paradox that the quarks in the 56-dimensional representation were in the symmetric permutation state, before I had even heard of the problem, because I had been playing around with other statistics just for the fun of it. *The seemingly useless knowledge that quantum mechanics allows statistics other than bose or fermi became useful in the context of the quark model.*

This was tantamount to introducing a new three-valued charge, now called "color." However, to suggest that quarks carry an unseen three-valued color charge strained credulity. The parafermi statistics would be hidden. The wave function of the quarks including the parastatistics factor would be antisymmetric as required by the exclusion principle and the spin-statistics connection. However, when the parastatistics wave function was factored out, the remaining wave function would be symmetric in the "visible" space-spin-$SU(\mathbf{3})_{flavor}$ degrees of freedom, and the quarks would behave as bosons in these visible degrees of freedom, as they did in the 56-dimensional representation of Gürsey and Radicati.[4]



Analogous to the way primary colors red, green, and blue light blend to create a perception of white light to the human eye, Greenberg's concept of color in quarks provides a means by which a combination of red, green, and blue "color charges" yield a color-neutral proton or neutron. Quarks and color were experimentally verified in 1973 and led to the standard model of particle physics that explains what the world is and what holds it together.

IMAGE COURTESY OF CAROLE KLIGER, DEPT. OF PHYSICS, UNIVERSITY OF MARYLAND

I GAVE A COPY OF MY PAPER TO ROBERT OPPENHEIMER . . . WHEN I ASKED HIM IF HE HAD READ IT, HE REPLIED, "GREENBERG, IT'S BEAUTIFUL! . . . BUT I DON'T BELIEVE A WORD OF IT!" . . . TO SUGGEST THAT QUARKS CARRY AN UNSEEN THREE-VALUED COLOR CHARGE SEEMED SPECULATIVE BEYOND REASON.

Since the paradox had arisen in the ground-state baryons, I worked out the consequences of the parafermi model for the excited states of the baryons as an independent test of this idea. I called this model the "symmetric quark model." I used a simple shell model in which the quarks in the ground-state baryons are in states with zero orbital angular momentum, "s states," and the first excitations have two quarks in *s* states and one in a "p" state with one unit of angular momentum.[5] I tabulated the properties of these resonances, as well as some higher resonances.

I gave a copy of the preprint of my paper to Robert Oppenheimer, who, as Director of the Institute for Advanced Study, was my host. A week later I met him at an Eastern Physics Meeting at the University of Maryland, my home institution. When I asked him if he had read my paper, he replied, "Greenberg, it's beautiful!" I was elated. After a pause, he completed his assessment of my paper by saying, "But I don't believe a word of it!" Although I was not discouraged by his negative opinion, I did not have the presence of mind to ask what his objection was. Unfortunately, Oppenheimer died before data that confirmed color as well as my model of baryons had been obtained. Further confirmation of the three-valued charge, now called "color," implied by parastatistics of order-3 came later.

Further consequences of color

The 3 of color appears in a simple way in the $\pi^0 \to 2\gamma$ decay represented by the anomalous triangle diagram with the π^0 connected to one vertex of the triangle via the axial current and with a photon at each of the other vertices. Quarks circulate around the triangle; each color contributes equally to the decay matrix element so that the decay matrix element is multiplied by a factor of 3 and the decay rate is multiplied by a factor of 9 relative to the results for color-singlet quarks. The factor of 9 for the decay rate agrees with experiment. It is amusing that the same matrix element and decay rate follow from integer-charged protons and neutrons circulating around the triangle. The color factor 3 also enters in the ratio of the cross sections $\sigma(e^+e^- \to hadrons)/\sigma(e^+e^- \to \mu^+\mu^-)$. Again, the factor 3 is required to agree with data. For these two examples, the parastatistics model agrees in lowest order with the now-standard gauge theory of color, quantum chromodynamics (QCD). The parastatistics model cannot be gauged because of the twisted commutation relations and fails to agree with experiment and with QCD in higher orders. As its name suggests, color enters in a fundamental way in QCD and the successful predictions of QCD confirm the existence of the color degree of freedom. Harald Fritzsch, Gell-Mann, and Heinrich Leutwyler gave a summary of the advantages of the color model.[6] Color also provides an explanation of "saturation": why the lowest mass hadrons are made of just two combinations, 3 quarks for baryons and a quark-antiquark pair for mesons. Daniel Zwanziger and I showed that only the three-valued color charge can explain saturation.[7]

Oppenheimer was not alone in being skeptical of color as well as of quarks. Particles with the fractional charges of the quark model had not been observed, nor have they been observed to this day. Suggesting that quarks carry a hidden three-valued color charge seemed speculative beyond reason. Quarks and color were not accepted by the physics community until the discovery of "naked" charm in 1975.

Oppenheimer and the Institute

Oppenheimer arranged lunches on Tuesday, the day of the weekly seminars, to which he invited members of the permanent Faculty at the Institute as well as faculty from Princeton University and also some visiting Members at the Institute. He arranged for sandwiches and fruit at these informal lunches in his office. During the conversations about physics, people would write things on the blackboard in his office. I noticed that Oppenheimer was very active in these discussions, but he never wrote anything on the board.

Oppenheimer presided at the Tuesday seminar, usually given by an outside speaker. Sometimes Oppenheimer made comments that anticipated what the speaker was about to say. He would then turn around and look back at the audience to see how his comments were received.

Although Oppenheimer was generally kind to me, he could be cruel to other physicists. On one occasion, a faculty member at Rutgers sat in the first row of the seminar room. When Oppenheimer entered he said, "That is not for you" to this person, whereupon the Rutgers faculty member moved to a seat in the back of the room.

I interacted with several of the visiting Members; in particular Ben Lee, John Cornwall, and Peter Freund, who had suggestions to generalize the $SU(\mathbf{6})$ model of Gürsey and Radicati, as well as Sam MacDowell and Korkut Bardaksi. I recruited Alex Dragt and Ching-Hung Woo for Maryland where they both became faculty members. The permanent Members I interacted most with were Freeman Dyson and Frank Yang.

The time I spent at the Institute was crucial for my development as a physicist. I did my most important work during that time and made lasting friendships with other colleagues. The atmosphere at the Institute, the frequent interaction with Members, the collegiality, and the seminars were highly conducive to doing original work. I think the culture of the Institute, then and now, is unparalleled for generating new ideas. ■

1 F. Gürsey and L. Radicati, *Physical Review Letters* 13, 173 (1964).

2 M.A.B. Beg, B.W. Lee, and A. Pais, *Physical Review Letters* 13, 514 (1964).

3 O.W. Greenberg and A.M.L. Messiah, *Physical Review* 136, B248 (1964).
Parafermi statistics of order *p* allows up to *p* particles to be in a symmetric state and any number to be in an antisymmetric state; for parabose statistics of order *p*, up to *p* particles can be in an antisymmetric state and any number can be in a symmetric state.

4 Just for fun, I performed the exercise of rewriting the $SU(\mathbf{6})$ multiplets discussed by Gürsey and Radicati in terms of parafermi quarks of order-3 and redid the magnetic moment calculation using the parafermi quark states.

5 O.W. Greenberg, *Physical Review Letters* 13, 598 (1964).
In this model, the 56-dimensional representation has 8 isospin multiplets with positive parity. The first excitations are in the 70-dimensional representation, which has 30 isospins with negative parity.

6 H. Fritzsch, M. Gell-Mann, and H. Leutwyler, *Physics Letters* 47B, 365 (1973).

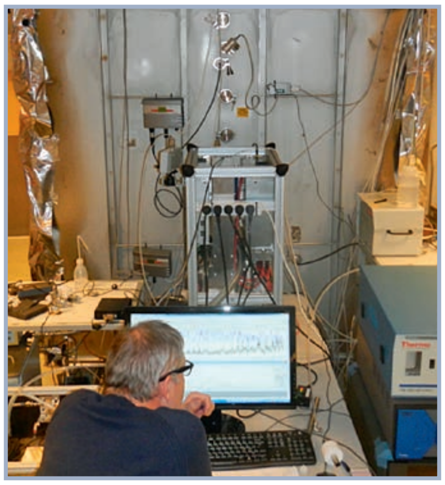
7 O.W. Greenberg and D. Zwanziger, *Physical Review Letters* 150, 1177 (1966).

MILKY WAY *(Continued from page 1)*

by supernova explosions that took place in the solar system's galactic neighborhood in the past twenty million years or so.

Besides being messengers from ancient explosions, cosmic rays are extremely interesting because they link together so many different phenomena. They tell us about the galactic geography, about the history of meteorites or of solar activity, they can potentially tell us about the existence of dark matter, and apparently they can even affect climate here on Earth. They can explain many of the past climate variations, which in turn can be used to study the Milky Way.

The idea that cosmic rays may affect climate through modulation of the cosmic ray ionization in the atmosphere goes back to Edward Ney in 1959. It was known that solar wind modulates the flux of cosmic rays reaching Earth—a high solar activity deflects more of the cosmic rays reaching the inner solar system, and with it reduces the atmospheric ionization. Ney raised the idea that this ionization could have some climatic effect. This would immediately link solar activity with climate variations, and explain things like the little ice age during the Maunder minimum, when sunspots were a rare occurrence on the solar surface.



NIR SHAVIV

Henrik Svensmark uses the gamma-ray irradiated chamber in the background to pinpoint the mechanism linking atmospheric ions and cloud condensation nuclei.

In the 1990s, Henrik Svensmark from Copenhagen brought the first empirical evidence of this link in the form of a correlation between cloud cover and the cosmic ray flux variations over the solar cycle. This link was later supported with further evidence including climate correlations with cosmic ray flux variations that are independent of solar activity, as I describe below, and, more recently, with laboratory experiments showing how ions play a role in the nucleation of small aerosols and their growth to larger ones.

In 2000, I was asked by a German colleague about possible effects that supernovae could have on life on Earth. After researching a bit, I stumbled on Svensmark's results and realized that the solar system's galactic environment should be changing on time scales of tens of millions of years. If cosmic rays affect the terrestrial climate, we should see a clear signature of the galactic spiral arm passages in the paleoclimatic data, through which we pass every 150 million years. This is because spiral arms are the regions where most supernovae take place in our galaxy. Little did I know, it would take me on a still ongoing field trip to the Milky Way.

The main evidence linking the galactic environment and climate on Earth is the exposure ages of iron meteorites. Exposure ages of meteorites are the inferred duration between their breakup from their parent bodies and their penetration into Earth's atmosphere. They are obtained by measuring the radioactive and stable isotopes accumulated through interaction with the cosmic rays perfusing the solar system. It turns out that if one looks at exposure ages a bit differently than previously done, by assuming that meteorites form at a statistically constant rate while the cosmic ray flux can vary, as opposed to the opposite, then the cosmic ray flux history can be reconstructed. It exhibits seven clear cycles, which coincide with the seven periods of ice-age epochs that took place over the past billion years. On longer time scales, it is possible to reconstruct the overall cosmic ray flux variations from a changed star formation rate in the Milky Way, though less reliably. The variable star formation rate can explain why ice-age epochs existed over the past billion years and between one and two billion years ago, but not in other eons.

I later joined forces with Canadian geochemist Ján Veizer who had the best geochemical reconstruction of the temperature over the past half billion years, during which multicellular life left fossils for his group to dig and measure. His original goal was to fingerprint the role of CO_2 over geological time scales, but no correlation with the paleotemperature was apparent. On the other hand, his temperature reconstruction fit the cosmic ray reconstruction like a glove. When we published these results, we instantly became personae non gratae in certain communities, not because we offered a data-supported explanation to the long-term climate variations, but because we dared say that CO_2 can at most have a modest effect on the global temperature.

Besides the spiral arm passages, our galactic motion should give rise to a faster cosmic ray flux modulation—in addition to the solar system's orbit around the galaxy, with roughly a 250-million-year period, the solar system also oscillates perpendicular to the galactic plane. Since the cosmic ray density is higher at the plane, it should be colder every time the solar system crosses it, which depending on the exact amount of mass in the disk should be every 30 to 40 million years.

A decade ago, the geochemical climate record showed hints of a 32-million-year periodicity, with peak cooling taking place a few million years ago, as expected from the last plane passage. Together with Veizer and a third colleague, Andreas Prokoph, we then submitted a first version for publication. However, we actually ended up putting the paper aside for almost a decade because of two nagging inconsistencies.

First, analysis of the best database of the kinematics of nearby stars, that of the Hipparcos satellite, pointed to a low density at the galactic plane, which in turn implied a longer period for the plane crossings, around once every 40 million years. Second, it was widely accepted in the cosmic ray community that cosmic rays should be diffusing around the galactic disk in a halo that is much larger than the stellar disk itself. This would imply that the 300 light years that the solar system ventures away from the galactic plane could not explain the 1 to 2°C variations implied for the geochemical record. Without a way to reconcile these, there was not much we could do. Perhaps the 32 million years was just a random artifact.

As time progressed, however, the improved geochemical record only showed that the 32-million-year signal became more prominent. In fact, fifteen cycles could now be clearly seen in the data. But something else also happened. My colleagues and I began to systematically study cosmic ray diffusion in the Milky Way while alleviating the standard assumption that everyone had until then assumed—that the sources are distributed symmetrically around the galaxy. To our surprise, it did much more than just explain the meteoritic measurements of a variable cosmic ray flux. It provided an explanation to the so-called Pamela anomaly, a cosmic ray positron excess that was argued by many to be the telltale signature of dark matter decay. It also explained the behavior of secondary cosmic rays produced along the way. But in order for the results to be consistent with the range of observations, the cosmic ray diffusion model had to include a smaller halo, one that more closely resembles the disk. In such a halo, the vertical oscillation of the solar system should have left an imprint in the geochemical record not unlike the one detected.

Thus, armed with the smaller halo and a more prominent paleoclimate signal, we decided to clear the dust off the old paper. The first surprise came when studying the up-to-date data. It revealed that the 32-million-year signal also has a secondary frequency modulation, that is, it is periodically either slower or longer. This modulation has a period and phase corresponding to the radial oscillations that the solar system exhibits while revolving around the galaxy. When it is closer to the galactic center, the higher density at the galactic plane forces it to oscillate faster, while when far from the center, the density is lower and the oscillation period is longer.

The second surprise came when studying the stellar kinematics from the astrometric data. We found that the previous analysis, which appeared to have been inconsistent, relied on the assumption that the stars are more kinematically relaxed then they are. As a consequence, there was a large unaccounted systematic error—without it there was no real inconsistency. It took almost a decade, but things finally fell into place.

The results have two particularly interesting implications. First, they bring yet another link between the galactic environment and the terrestrial climate. Although there is no direct evidence that cosmic rays are the actual link on the 32-million-year time scale, as far as we know, they are the only link that can explain these observations. This in turn strengthens the idea that cosmic ray variations through solar activity affect the climate. In this picture, solar activity increase is responsible for about half of the twentieth-century global warming through a reduction of the cosmic ray flux, leaving less to be explained by anthropogenic activity. Also, in this picture, climate sensitivity is on the low side (perhaps 1 to 1.5°C increase per CO_2 doubling, compared with the 1.5 to 4.5°C range advocated by the Intergovernmental Panel on Climate Change, implying that the future is not as dire as often prophesied.

The second interesting implication is the actual value of the 32-million-year oscillation. The relatively short period indicates that there is more mass in the galactic plane than accounted for in stars and interstellar gas, leaving the remainder as dark matter. However, this amount of dark matter is more than would be expected if it were distributed sparsely in a puffed-up halo as is generally expected. In other words, this excess mass requires at least some of the dark matter to condense into the disk. If correct, it will close a circle that started in the 1960s when Edward Hill and Jan Oort suggested, based on kinematic evidence, that there is more matter at the plane than observed. This inconsistency and indirect evidence for dark matter was also advocated by John Bahcall, who for many years was a Faculty member here at the IAS.

It should be noted that the idea that cosmic rays affect the climate is by no means generally accepted. The link is contentious and it has attracted significant opponents over the years because of its ramifications to our understanding of recent and future climate change. For it to be finally accepted, one has to understand all the microphysics and chemistry associated with it. For this reason, we are now carrying out a lab experiment to pinpoint the mechanism responsible for linking atmospheric ions and cloud condensation nuclei. This should solidify a complete theory to explain the empirical evidence.

As for the existence of more dark matter in the galactic plane than naively expected, we will not have to wait long for it to be corroborated (or refuted). The Gaia astrometric satellite mapping the kinematics of stars to unprecedented accuracy will allow for a much better measurement of the density at the plane. The first release of data is expected to be in 2016, just around the corner. ■

Nir Shaviv, IBM Einstein Fellow and Member in the School of Natural Sciences, is focusing on cosmic ray diffusion in the dynamic galaxy, the solar cosmic ray–climate link, and the appearance of extremely luminous (super-Eddington) states in stellar evolution during his stay at the Institute. Shaviv is Professor at the Racah Institute of Physics at the Hebrew University of Jerusalem.

Save the Date: America's First National Math Festival Comes to D.C. on April 18

The Mathematical Sciences Research Institute (MSRI) and the Institute for Advanced Study announced the inaugural National Math Festival that will take place in Washington, D.C., on Saturday, April 18, from 10 a.m. to 4 p.m.

The free public celebration, co-organized by MSRI and IAS in cooperation with the Smithsonian Institution, will feature more than thirty unique performances, interactive exhibits, and lectures, with activities to engage toddlers through lifelong learners. Events will take place at the Smithsonian's Enid A. Haupt Garden, the S. Dillon Ripley Center, the National Museum of Natural History, the National Air and Space Museum, the National Museum of African Art, and the Freer and Sackler Galleries, among others.

national math festival

"Math is all around us—from the colors of the rainbow to the cars we drive and the bridges they drive over, from modern cell phones and Internet commerce to the newest medical technology, from the study of the deep oceans to the study of the stars," said David Eisenbud, Director of the Mathematical Sciences Research Institute. "This festival is a celebration of math in all its fun and beauty: math everyone can understand and enjoy."

Featured elements of the National Math Festival include a nationally acclaimed collection of more than twenty interactive exhibits devised by the National Museum of Mathematics; a contest, "Who Wants to Be a Mathematician?" for high school students; Ooblek Olympics, a mathematics-themed obstacle course through the Smithsonian Institute's Enid A. Haupt Garden; a roving troupe of topological Houdinis; an interactive, artistic introduction to the curved loops and geometric symmetry of South Indian painting; and an expert-led, illustrated journey through Islamic architecture from the Alhambra to the Taj Mahal.

Designed to appeal to math lovers of all ages, the National Math Festival will also feature some of the most influential mathematicians of our time. Among the featured presenters: Kenneth Golden, Professor of Mathematics and Adjunct Professor of Biomedical Engineering at the University of Utah; Richard Tapia, Professor of Mathematics at Rice University; and Steven Strogatz, Jacob Gould Schurman Professor of Applied Mathematics at Cornell University.

"Through these exciting lectures, performances, and hands-on activities, the Festival will also highlight the possibilities that exist through math, and the fun it inspires," said Robbert Dijkgraaf, Director and Leon Levy Professor. "Research by mathematicians everywhere is important in expanding our understanding of the world, and we are immensely proud to partner in this celebration to encourage and support the math of today and tomorrow."

The National Math Festival has received generous support from the Carnegie Corporation of New York, Google, Howard Hughes Medical Institute, the Simons Foundation, The Charles and Lisa Simonyi Fund for Arts and Sciences, the Alfred P. Sloan Foundation, The Kavli Foundation, the Gordon and Betty Moore Foundation, the Research Corporation for Science Advancement, and IBM. Additional support is provided by the National Museum of Mathematics (MoMath), NOVA, and the Elwyn and Jennifer Berlekamp Foundation.

For more information, visit www.mathfest.org. ■

Murph Goldberger (1922–2014)

INSTITUTE FOR ADVANCED STUDY

Murph Goldberger

Marvin L. "Murph" Goldberger, who served as the Institute for Advanced Study's sixth Director from 1987–91, died on November 26 at the age of ninety-two. A prominent physicist with a distinguished career in higher education, he was most recently Professor at the University of California, San Diego. During his tenure as Director at the Institute, Goldberger created positive growth and change through Faculty appointments and campus building projects, among other initiatives.

Goldberger believed deeply in the Institute's mission, and observed in 1990: "On balance, a modern-day Flexner, provided he or she were smart enough, wouldn't go too far wrong to reinvent the Institute largely unchanged in overall form … a truly civilized society should be prepared to support the highest form of pure intellectual endeavor without regard for immediate practical applications."

Edward Witten, Charles Simonyi Professor in the School of Natural Sciences, noted: "Murph was an extremely eminent physicist who made celebrated contributions to pion physics, dispersion relations, and scattering theory. At a personal level, he was an important mentor to me. When I came to Princeton as a graduate student, his quantum mechanics course was one of the first courses I took, and I learned a lot from him through my graduate school days and afterwards. Murph was also highly distinguished as a national leader in science policy." ■

New Leadership Appointments

NARAYANA MURTHY APPOINTED TO BOARD

INFOSYS

Narayana Murthy

The Institute for Advanced Study has appointed Narayana Murthy to its Board of Trustees, effective October 25, 2014. Mr. Murthy is the Founder of Infosys Limited, a global consulting, technology, and outsourcing services company based in Bangalore.

As CEO of Infosys for twenty-one years, Murthy designed and implemented the Global Delivery Model, which has become the foundation for success in IT-services outsourcing from India. He has led key corporate governance initiatives in India and is an IT advisor to several countries. Murthy is also President of the Infosys Science Foundation, which governs the Infosys Prize, an annual award to honor outstanding achievements of researchers and scientists, and he serves on the boards of leading foundations, including the Ford Foundation, the Rhodes Trust, and the U.N. Foundation.

Murthy received his undergraduate education at the University of Mysore in India and earned his M.A. in engineering from the Indian Institute of Technology Kanpur. He has received many awards for his achievements, including the Hoover Medal from the American Society of Mechanical Engineers and the Ernst Weber Medal from the Institute of Electrical and Electronics Engineers. Murthy is also a Foreign Member of the U.S. National Academy of Engineering and a Fellow of the Indian National Academy of Engineering. ■

KRISTEN GHODSEE ELECTED AMIAS PRESIDENT

Kristen Ghodsee

Kristen Ghodsee, Professor of Gender and Women's Studies at Bowdoin College, was elected President of the Board of Trustees of the Association of Members of the Institute for Advanced Study (AMIAS). As President, Ghodsee, former Member (2006–07) in the School of Social Science, will lead the AMIAS Board in its works on behalf of the Institute and current and former Members. She succeeds Stephen Mansbach, who served as President from 2012–14.

"I am very honored to have this opportunity to serve the AMIAS community," said Ghodsee. "The association does such valuable work in supporting Members and their families while in residence and promotes communication and collaboration among Members after their visit to the Institute. AMIAS is a wonderful way to stay involved in the Institute community."

Four new Board members were also elected at the AMIAS Annual Meeting of the Members, including Alison I. Beach, Associate Professor of History at the Ohio State University; Duana Fullwiley, Associate Professor of Anthropology at Stanford University; Claudia Swan, Associate Professor of Art History at Northwestern University; and Nancy J. Troy, Victoria and Roger Sant Professor in Art and Department Chair at Stanford University. Additionally, Bruce Grant, Professor of Anthropology at New York University and Julia Wolf, Helibronn reader in combinatorics and number theory at the University of Bristol, were reelected to serve a second term on the Board. ■

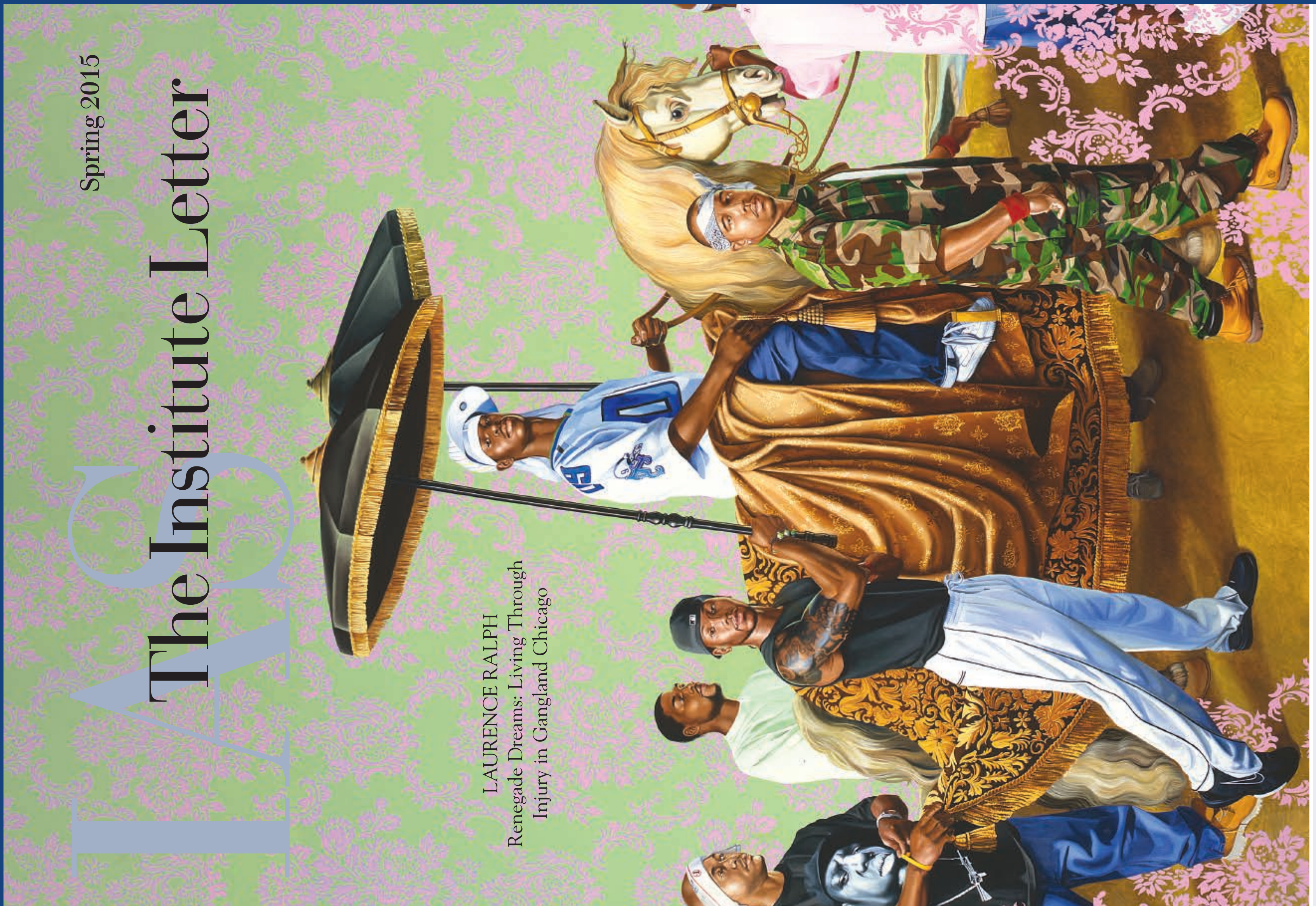
RAFE MAZZEO APPOINTED DIRECTOR OF PCMI

Rafe Mazzeo

The Park City Mathematics Institute (PCMI) is celebrating its twenty-fifth anniversary, new leadership, and several positive funding developments. Founded through a grant from the National Science Foundation, PCMI has been an Institute outreach program since 1994, bringing together some three hundred mathematics researchers, K–12 teachers, and graduate and undergraduate students and faculty for professional development.

Rafe Mazzeo, Professor in the Department of Mathematics at Stanford University and Faculty Director of the Stanford Pre-Collegiate Studies program, has been appointed the new Director of PCMI, succeeding Richard Hain, Professor at Duke University and Member in the School of Mathematics. Mazzeo's research interests include geometric and microlocal analysis and partial differential equations, and he received both his Ph.D. and B.S. from the Massachusetts Institute of Technology. He has received many awards, including fellowships from the National Science Foundation and the Alfred P. Sloan Foundation, and he serves on the editorial boards of several journals.

PCMI has recently received renewed support from the National Science Foundation (through July 2019), the National Security Agency (through 2015), and Math for America (through 2015). PCMI also was awarded a three-year $1 million grant from a private foundation to support its K–12 Teacher Leadership program, and it was selected for membership in the 100K in 10, an initiative designed to provide America's classrooms with 100,000 excellent STEM teachers by 2021. ■



NIR SHAVIV
A Field Trip Through the Milky Way

HASSAN ANSARI
The Necessity of a Historical Approach to Islamic Theology

CÉDRIC VILLANI
The Birth of a Theorem

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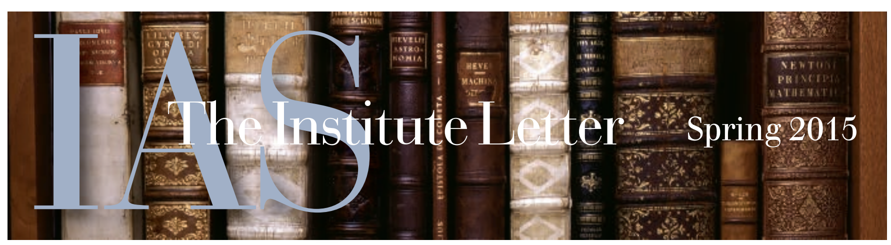

BRUCE M. WHITE

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