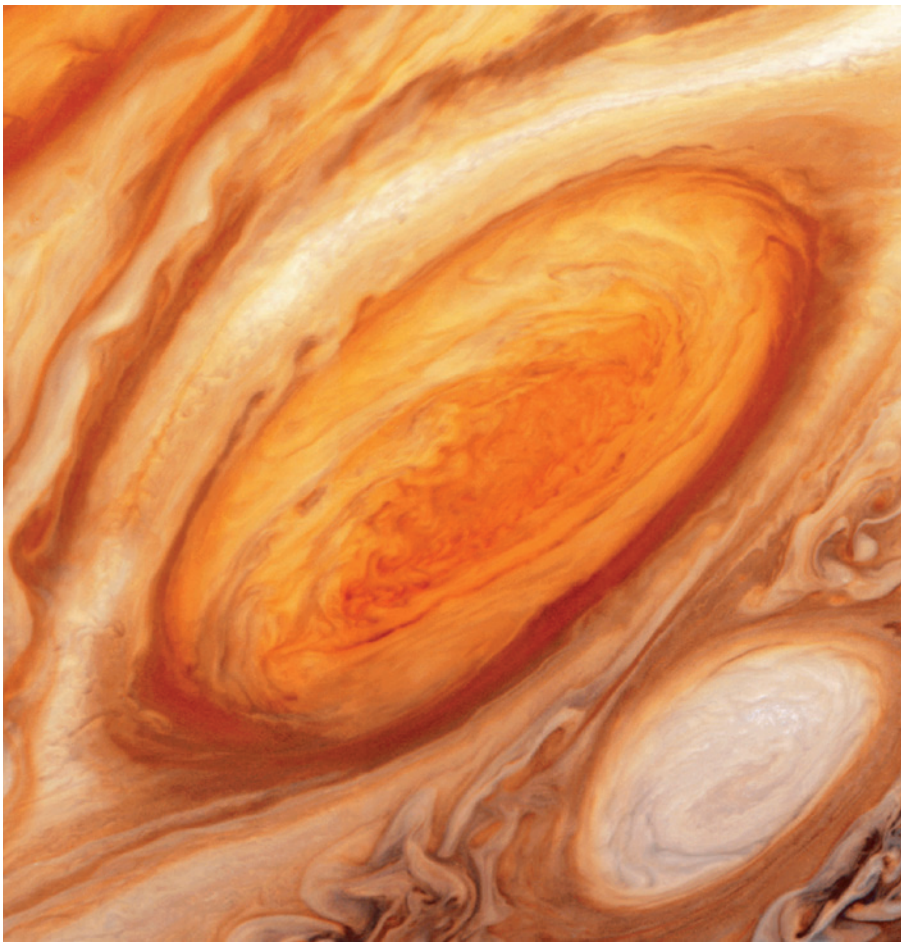
SPACE SCIENCE

Beyond the heliopause

Roger D. Launius savours a masterful account, by a veteran of interplanetary space science, of the Voyager probes' mission to the giant planets.



Jupiter's Great Red Spot, a massive stable storm photographed by Voyager 2 in 1979.

NASA/SPL

Part memoir, part anecdotal history and part sermon on the delights of science, *The Interstellar Age* is a captivating read. In it, planetary scientist Jim Bell presents the eventful story of NASA's Voyager 1 and Voyager 2 missions to the edge of the Solar System and beyond. Bell, a veteran of many space-science missions, including several Mars probes, brings deft writing and an in-depth, nuanced understanding of big planetary-science efforts to this popular account.

Voyager's legendary status has been long assured, although *The Interstellar Age* will add to its cachet. Conceived in the 1960s and launched in the 1970s, the twin probes encountered the larger outer planets of the Solar System — Jupiter, Saturn, Uranus and Neptune — between the late 1970s and the late 1980s. Having gone far beyond their original remit, they now continue an interstellar mission at the edge of the Solar System. The probes are, in essence, 'the little spacecraft that could'.

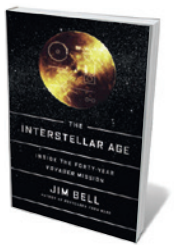
Bell writes about how, in the early 1960s, aerospace engineer Gary Flandro and other scientists realized that once every 176 years, Earth and the Solar System's four giant planets gather on one side of the Sun. This would enable close-up observation of the giants, in a planetary 'grand tour'. During the fly-by of each planet, a gravity assist — a slingshot effect, harnessing the planet's movement and gravity — could increase the spacecraft's velocity and reduce flight times.

Bell describes the politics of the planning stage. The four-planet scenario was possible, but NASA deemed it too expensive to build a spacecraft for an extended mission. Voyager was downgraded to a Jupiter–Saturn fly-by, but engineers designed as much longevity into the probes as the US$875-million budget would allow. NASA launched Voyager 2 on 20 August 1977, and Voyager 1 followed on a faster, shorter trajectory on 5 September.

Bell, who hung out with the science team as an undergraduate at the California Institute of Technology in Pasadena, describes how the craft achieved their objectives — and then some. Voyager 1 was, for example, programmed for a close encounter with Saturn's moon Titan, during which it revealed a complex world with an atmosphere, thick clouds and water ice. It showed that Titan was ripe for scientific investigation, paving the way for the sustained investigations of the Huygens–Cassini mission at the dawn of this century. But this fly-by deflected Voyager 1 out of the Solar System's elliptical plane; unable to continue on to Uranus and Neptune, the craft's planetary mission ended.

Voyager 2 continued on to the two outermost giant planets. Bell reports how, as the probes flew, controllers constantly reprogrammed the on-board computers, which had only about 5,000 words' worth of memory each, to take advantage of scientific opportunities. Successfully capturing data was hugely taxing, but mission engineers and scientists made it work.

The probes explored the giant planets' systems of rings and magnetic fields, finding previously unknown geological activity on Io, a moon of Jupiter with numerous volcanic features. The Voyagers also explored a total of 48 moons around the gas giants. They sent back more than 100,000 images of the planets, rings and satellites, and took magnetic measurements, chemical spectra and radiation readings. The information revolutionized Solar System science, helping to resolve key questions about how it was formed and raising intriguing new ideas such as the possibilities of life beyond Earth.



The Interstellar Age: Inside the Forty-Year Voyager Mission
JIM BELL
Dutton: 2015.

Bell is at his best in telling the human

The identical Voyager probes launched in 1977 and are still travelling.

NASA/JPL/SPL

stories of discovery, excitement and public engagement. He describes the extension of the Voyager mission to the heliopause, where the Sun's energy is overpowered by interstellar forces. Ed Stone, who has been chief scientist for Voyager since its inception, evinced the excitement of a self-confessed non-party animal. "I can still remember taking the data home every night, and putting the plots on the refrigerator," he tells Bell. "I couldn't stop thinking about them, wondering what would happen next."

Voyager 1 is now more than 130 astronomical units (AU) from the Sun (1 AU is the distance between the Sun and Earth, around 150 million kilometres), and Voyager 2 is at more than 107 AU. They continue to take readings of the heliopause.

JOEL SAGET/AFP/GETTY

Thanks to astronomer Carl Sagan, one of Bell's heroes, both probes contain messages from Earth: gold-plated copper phonograph records encoded with 115 images of scenes from Earth, audio greetings in 55 languages, and 90 minutes of music from Bach to Chuck Berry, along with playing instructions. This message in a bottle is one of the mission's best-known attributes, and Bell explains well its publicity value and how it represents a feel-good sentiment about the possibility of encountering interstellar life.

The Voyagers demonstrate the remarkable advances in robotic space exploration over the past almost 40 years, and suggest that subsequent missions may yield even more exciting results. Such follow-ups as the Galileo mission to Jupiter, Huygens–Cassini to Saturn and New Horizons to the Kuiper belt including Pluto may herald even more ambitious missions — to Titan, for instance, where they might sail on a hydrocarbon sea, or to Jupiter's moon Europa, to explore an ice-covered liquid-water ocean that has the potential to harbour life.

I believe that NASA's greatest achievement is the Apollo Moon programme. The odyssey of the Voyagers certainly vies for second place. Bell appropriately quotes historian Stephen Pyne: "The Voyagers were special when they launched. They have become more so thanks to their longevity, the breadth of their discoveries, the cultural payload they carried, and the sheer audacity of their quest." ■

Roger D. Launius *is associate director for collections and curatorial affairs at the Smithsonian Institution's National Air and Space Museum in Washington DC.*
e-mail: launiusr@si.edu

MATHEMATICS

Groping in the dark for glimpses of beauty

Amir Alexander relishes two accomplished accounts of the life mathematical.

One evening in 2009, French mathematician Cédric Villani stepped into his children's room. He locked the door, turned off the light and began to pace, pondering the statistical properties of plasma. A few metres away, his wife, Claire, was in the kitchen, cooking dinner for the family. The contrast, Villani concedes in his engaging *Birth of a Theorem*, was "a bit much", yet immediately after dinner he returned to the dark room to grapple for hours with his elusive proof.

Anyone reading that anecdote will feel sympathy for Claire as she tries to preserve family normality. Anyone who has seriously engaged with mathematics will also understand her husband. Perhaps more than any other field, mathematics pulls the practitioner away from the 'normal' world of things and people into a strange alternate universe, in which we catch glimpses of beauty and coherence, but spend most of our time groping in the dark. In *Birth of a Theorem*, Villani offers one way of straddling that divide; in *Mathematics Without Apologies*, fellow mathematician Michael Harris presents a very different one. Together, they provide an unmatched perspective on life in this "problematic vocation" by two of its leading practitioners.

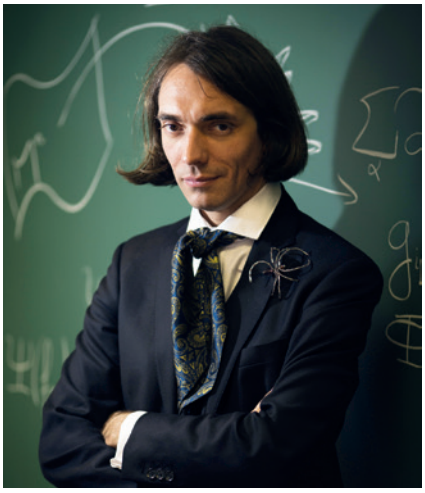
Birth of a Theorem is the story of Villani's quest to give a full mathematical account of Landau damping. Whereas gas becomes increasingly disordered over time as entropy increases, plasma spontaneously stabilizes, with no increase in entropy. Soviet physicist Lev Landau was the first to mathematically describe this improbable phenomenon, but he used a simplified model that left many unconvinced. Working closely for several years with mathematician Clément Mohout, Villani succeeded, and he was awarded a Fields Medal in 2010.

Villani's quest takes him across the world, from Lyons, France, to Princeton, back to Paris and on to Hyderabad in India. At every stop, he talks to local mathematicians, demonstrating that, for all its abstractness, mathematics can be an intensely social activity. The book is sprinkled with brief, telling portrayals of mathematicians and physicists past and present. The grumpy, grey-haired Étienne Ghys of Lyons and Chinese expat Alice Chang of Princeton alternate with the autocratic Lev Landau in 1960s Moscow and the ever-present shadow of Albert Einstein at the Institute for Advanced Study in Princeton. Much of Villani's e-mail correspondence with Mohout is reproduced, chronicling moments of triumph and despair.

Charismatic and flamboyantly dressed, Villani is the opposite of the 'mathematical hermit' and annoyed by the stereotype. He attends a recital by one of his children, joins his family at the American Museum of Natural History in New York and travels a long way to attend a concert by rock band Têtes Raides. Yet he studies the mathematics of galaxy formation during the recital, works out a step in his proof on the bus from the museum, and explains his research to a stranger who drives him back from the concert. The mathematical life, in his telling, is a delicate dance between the demands of the 'real' world and the ▶

Birth of a Theorem: A Mathematical Adventure
CÉDRIC VILLANI
Bodley Head/Faber and Faber: 2015.

Mathematics Without Apologies: Portrait of a Problematic Vocation
MICHAEL HARRIS
Princeton Univ. Press: 2015.



Cédric Villani studies the maths of plasmas.

➲ NATURE.COM
For more on science in culture, see:
nature.com/booksandarts