BOOK REVIEW
The Wraparound Universe by Jean-Pierre Luminet, A. K. Peters

Amanda Gefter, New Scientist magazine, 16 February 2008, page 46

The cosmic mollusc

This beautiful book on the possibility that our universe is a huge optical illusion will change the way you look at the sky, says Amanda Gefter

As a teenager, French astrophysicist Jean-Pierre Luminet read about the curved space of Einstein's general relativity. One passage in an astronomy book struck him: the universe, it said, could be shaped like a mollusc. "In my imagination," Luminet writes, "the space-time mollusc gave birth to a picturesque vision of an immense cosmic snail, its skin streaked through with light, variegated in bends and curves. From then on, I have never stopped seeking to clarify this strange assertion - what is this universal mollusc? - and I have never again looked the same way upon the beautiful skies of my native Provence."

That experience stayed with him when, in 2003, NASA's WMAP satellite gave cosmologists their first detailed picture of the newborn universe. WMAP measured tiny fluctuations in the cosmic microwave background (CMB) radiation - relic heat from the big bang. The data seemed to confirm what had become the accepted model in cosmology: the universe began with a big bang, followed by a brief period of faster-than-light expansion known as inflation. But one feature left everyone puzzled. If inflation happened, there should be variations in the CMB at all scales. The WMAP data, however, showed no fluctuations at scales larger than 60 degrees across the sky.

Soon after, a paper by Luminet and his colleagues was featured on the cover of *Nature* and sparked a media frenzy. The CMB anomaly, Luminet claimed, could be explained if the universe were finite, small and wrapped around itself in such a way that if you were to travel away from Earth in one direction you would eventually return from another. Perhaps there are no large-scale fluctuations in the CMB because space isn't large enough to hold them. According to Luminet, the data implied a universe folded like a dodecahedron, and the headlines cheered: "The universe is shaped like a soccer ball!"

Luminet's book *The Wraparound Universe* was originally published in French in 2001, two years before the WMAP results were released. Now it is appearing for the first time in English with an extended afterword. Sophisticated and beautifully written, the book is a thorough and enjoyable introduction to cosmic topology, the study of the global structure of space.

In a wraparound universe, the sky is an immense optical illusion, a hall of mirrors that makes space appear larger than it is. A galaxy's light can circle the universe many times, so a single galaxy can appear as multiple bright images across the sky. What seem to be different galaxies shining in the night sky might be "ghosts", copies of a single image. Such copies are hard to identify, however. Multiple images of a single galaxy won't look identical because they show the same galaxy at different times and from different angles. So far, astronomers haven't found any ghosts, but vast portions of the sky remain unexplored.

As well as ghost hunting, physicists can look for patterns in the CMB radiation that repeat across the sky. The soccer-ball model predicts six pairs of matched circles. Last year, physicists at Imperial College London raked the CMB for these circles and came up empty-handed. Last month, a team of Polish astronomers announced they had found them, though there is a small chance the matches are a fluke. The debate over the shape of the universe remains as lively as ever.

As I was reading, I found the structure of the book a bit strange. The first half flows naturally, but the second half is full of brief chapters whose topics circle back to ideas introduced earlier in the book. Then I realised that Luminet is playing a sort of game - like the soccer-ball universe, the book itself has an unusual topology.

If the universe turns out to be wrapped around itself, cosmologists will have to rethink cosmic history. Inflation should have stretched space out to enormous proportions, with our observable universe representing only a tiny region. If the entire universe is smaller than we see it, inflation is ruled out. Of course, that's no reason not to search for the telltale ghosts and circles.

"Thirty years after my first contemplations of the night sky of Provence," Luminet writes, "when I lift my head once again toward the starry firmament, I do not see the same thing. Twenty years of questioning about the shape of space have changed my gaze. In the sky, one can only see what one is prepared to see."

From issue 2643 of New Scientist magazine, 16 February 2008, page 46

BOOK REVIEW

The Wraparound Universe, Jean-Pierre Luminet, 2008 AK Peters

Wojtek J Zakrzewski, 2008 J. Phys. A: Math. Theor. 41 479001

I thoroughly enjoyed reading this book. It is written in clear language supplemented with many very helpful photographs and drawings. I like the structure of the book, which is a collection of 45 rather short chapters that make it easier for the reader to read it at his/her own speed.

The main aim of the author is to interest the reader in cosmology and to convey to him/her the amazing progress that has been made in recent years in our understanding of the universe, its shape and its future. However, even to formulate this problem and to describe some recent work in this field, the author has to explain to the reader many concepts from mathematics and physics. Jean-Pierre Luminet, in addition to being a well known astrophysicist, is also a very gifted writer and so he manages to do this very successfully. In fact the book contains very few formulae and most of the explanations are given in terms of a written narrative supplemented by drawings. The author is also extremely skillful in finding and then using appropriate analogies. The required ideas from mathematics, and topology in particular, present a further aim of the book—to explain to the interested reader the beautiful world of topology and its relevance to the description of the real world. Here, again, he succeeds very impressively.

The central claim of the book is as follows: instead of a simple topology, the Universe may have a multiply-connected topology—hence 'wrapped around'; in consequence, it may be much smaller than is usually assumed. If this is so some of the galaxies we see are not real galaxies, but only images of a smaller number of genuine galaxies. The author then discusses possible topologies, and finally chooses the 'dodecahedral' one. A large part of the book is dedicated to showing how this hypothesis can be tested, and what the most recent data on the cosmic background radiation from the WMAP satellite say about this issue (they are inconclusive). Jean-Pierre Luminet's suggestions disagree with the standard inflationary model, which uses the same data to argue that the Universe is spatially flat, and so infinite.

The author is also scrupulous in apportioning priorities. As he explains in detail in several historical sections, the standard cosmological equations (normally called Robertson Walker, or Friedmann Robertson Walker equations) were first written by Lemaitre and Friedmann—hence in the book the cosmological models which use them are always referred to as Friedmann–Lemaitre models. Similarly, the Doppler effect becomes the Doppler–Fizeau effect and Hubble's law is entitled Hubble–Lemaitre.

I also liked the sections of the book in which the author shows how the same ideas in different historic or geographic conditions have had different impacts on the development of science; some were ignored, some misunderstood and some considered more seriously than they deserved.

All in all, 'The Wraparound Universe' is a great general-audience book and I recommend it unreservedly.

Wojtek J Zakrzewski
Department of Mathematical Sciences Science Laboratory, University of Durham

BOOK REVIEW
The Wraparound Universe by Jean-Pierre Luminet, AK Peters.

Diego Casadei, CERN Courier, Aug 19, 2008.

The first thing that impressed me about this book by Jean-Pierre Luminet is the way the text is organized. Although the author seems to suggest that the reader uses the references as a way to jump between different chapters - rather like hyperlinks on the web - what I really appreciated is that the book has 45 short chapters, just a few pages long. This allows the reader to taste and digest it bit by bit, following his own rhythm. Because Luminet has done his best to explain everything in a simple but never simplistic way, it may take different people a different amount of time and this structure makes it easier to adapt to each reader's needs. This could be one of the reasons why the book had two editions in the original French as well as this English translation, and will probably be translated into other languages.

If you know a little of modern cosmology, you will read this book avidly from the first page to the last. I should admit that I felt ignorant at the very beginning, because I had never realized the importance of topology when discussing cosmic evolution (the fact that apparently I was not alone is not a good excuse). Hence I'm grateful to Luminet for having made the role of topology in modern cosmology very clear. For example, I learned that the finite or infinite character of space depends both on its curvature and on its topology, though the latter is often neglected, even in refereed papers published by important journals. In addition, I realized that Einstein's equations do not set constraints a priori on the universe's topology. Rather, they can be solved for different boundary conditions, which include the specification of the 3-dimensional space topology.

Space may have positive, null or negative curvature – a property of the "metric" that encodes the machinery to measure distances. We say that the geometry is spherical, Euclidean or hyperbolic in these three cases. The metric is the subject of Einstein's equations, which express it as a function of the total energy content of the universe through the energy-momentum tensor and the cosmological constant. On the other hand, the equations do not constrain the topology of the universe at all.

The simplest topology is "simply connected" (i.e. we can shrink all closed loops down to points without "exiting" from the space), and this is often implicitly assumed in books and articles about cosmology. However, "multiply connected" topologies are also possible (with any curvature), and if their "volume" is smaller than the visible universe they may leave distinct signatures on the cosmic microwave background radiation, which could be experimentally detectable.

In general, a multiply-connected universe would produce several images of each galaxy, and different topologies would produce different patterns, although searching for them is not an easy task. Luminet shows that the most recent data about the cosmic

background radiation from the Wilkinson Microwave Anisortopy Probe are fit better by "well-proportioned spaces", among which the best seems to be the "spherical dodecahedral Poincaré space", whose volume is 120 times smaller than the hypersphere (i.e. the simply-connected topology) with the same curvature. This conclusion has been criticized by many researchers, but cannot be falsified with the present data. However, the Planck satellite should be able to provide measurements precise enough to discard this possibility if wrong and, possibly, identify the actual topology of our universe.

Luminet also considers the sociology of science. Comments about the impact of different ideas or even about the same ideas in different historic and geographic conditions are scattered throughout, especially at the end. In conclusion, the book is well within the reach of the general public, but still offers valuable insights to more expert people. It raises a number of questions and tries to provide a few answers in one of the most fascinating subjects of modern research.

Diego Casadei, New York University and CERN.

BOOK REVIEW Exciting and Attractively Written

The Wraparound Universe

by Jean-Pierre Luminet
A.K. Peters, 2008, 336 pp, $39.00
ISBN 978-1-56881-309-7

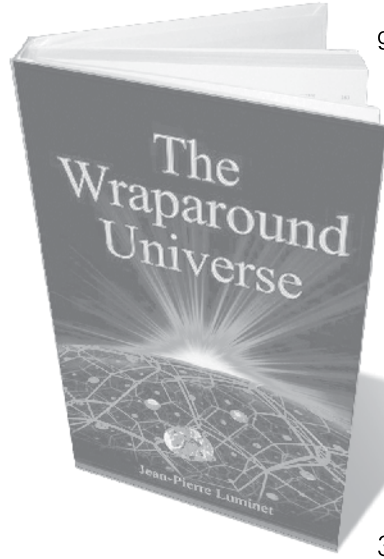
Review by G.W. Gibbon, Cambridge University

All cosmologists agree that to lowest approximation, at any given ('cosmic') time, the geometry of three-dimensional space is given locally by one of the three congruence geometries: Hyperbolic space, Euclidean space, or Spherical space. The galaxies and clusters are at rest with respect to these spaces but the distances between them increase uniformly in proportion to a universal function of time called the scale factor. This basic and extremely well verified observational fact is referred to as the Hubble expansion, after the first person to discover it, some ten years after Einstein's formulation of General Relativity in terms of the pseudo-Riemannian geometry of four-dimensional spacetime. In this picture, due to Friedmann and Lemaître, spacetime is a product of time with spatial sections of constant time corresponding to our traditional notion of space. Thus were the epic labours of Lobachevsky, Bolyai, Gauss, Klein as well as Clifford and Cayley and many others on the foundations of geometry neatly incorporated into a fully relativistic and consistent dynamical theory of gravitation.

Among the many things that cosmologists disagree about is not only which of these three possibilities holds, i.e. whether the spatial curvature is negative, zero or positive respectively, but what is the global geometry of the spatial sections. Do we take the simply connected covering spaces or should we identify under some discrete subgroup of the isometry group? If the curvature turns out to be positive, for example, should we take it to be given by the three-sphere, by real projective space, or even some more exotic space such as Poincaré's famous dodecahedral space?

The author of this exciting and attractively written book, unlike many of his colleagues, holds that observations indicate that the fundamental group of our universe is perhaps the binary dodecahedral group and so our space is a homology sphere. If true, then indeed Poincaré did not labour in vain.

What is perhaps more important than the disagreement is the agreement that what has hitherto been a purely metaphysical debate is now a matter for observation to decide. The fact that the universe is expanding means that it was hotter and denser in the past and among the relics of that hot early state are the 3-degree Kelvin Cosmic Microwave Background (CMB) photons. Satellite and balloon observations, with acronyms like COBE, BOOMERANG, MAXIMA and WMAP, have been used to place limits on the curvature and fundamental



group of the universe. The so-called concordance models are consistent with a flat spatial geometry and place lower limits on any repeat distance but certainly do not definitively exclude what the author calls a "wraparound universe". Indeed certain puzzling features of the data, if real, cannot easily be explained on the concordance model. With the launch of the PLANCK satellite on 31 October of this year, we shall have even more accurate and precise observations and almost certainly will be able to check the dodecahedral hypothesis. Since anything but zero curvature and no identifications is difficult to reconcile (but not absolutely impossible) with the fashionable theory of inflation, there is much at stake here.

These are indeed exciting times for those interested in the interface between physics and geometry. The author is to be thanked for providing a timely update of the first 2001 French edition, translated into English. The material, which is treated intuitively, is very well presented at a popular level, with many fascinating historical and sociological asides. It should be accessible to any first-year undergraduate or sixth-former. It would certainly be of interest as supplementary reading to anyone taking a first course in geometry or relativity and should appeal to any mathematically literate person in search of the 'Big Picture'.

Reprinted from the Newsletter of the LMS, Sept. 2008.

NOUVELLES DU DEPARTMENT

Wilfrid Laurier University, Waterloo, ON

Promotions:
Yongzeng (George) Lai (Associate Professor, July 1, 2008)

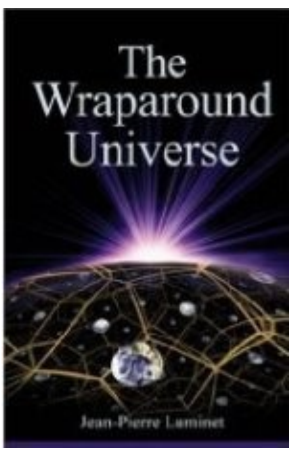
Appointments:
Anne-Marie Allison, (Assistant Professor, Applied Mathematics, July 1, 2008); Amal Amleh (Assistant Professor, Applied Mathematics, July 1, 2008).

Resignations:
Dr. Anthony Bonato (July 1, 2008)

September 2008
Reviews

'The wraparound universe'

reviewed by Richard Allen



The wraparound universe

Jean−Pierre Luminet

With Einstein's publication of *The Foundation of the General Theory of Relativity* in 1916 our view of the nature of the Universe was forever altered. General relativity, a spectacularly aesthetic theory, describes how the spacetime of the Universe is altered by its very contents; energy and matter. In Einstein's theory energy and matter curve space (and time) around them. What, then, is the exact shape of the Universe?

The equations of general relativity are rather difficult to solve, however it was soon realised that it is possible to model the whole Universe if certain assumptions are made: that the Universe is *isotropic* (it has no special directions, like an axis of rotation for example) and that the Universe is *homogenous* (on average the Universe is physically similar at every point, for example the average matter density is the same in all regions). If these assumptions hold true, they have an important consequence for models of the Universe: if matter (and energy) is, on average, distributed evenly throughout the Universe, then the Universe must have constant average curvature. Furthermore, the dynamics of the Universe (whether it is expanding, static or contracting) depend on the density of matter.

Jean−Pierre Luminet's *The wraparound universe* is a fascinating tour of modern models of the Universe, with particular emphasis on Luminet's own research on the topology of the Universe. Topology is the study of shapes, but with the idea of distance thrown away; a bracelet is topologically equivalent to a coffee mug because we can remould the mug as long as we maintain the hole formed by the handle, whereas we could never make a football because the hole would always remain. As Luminet suggests, the topology of the Universe is one of its important properties, for it determines whether space is finite or infinite.

Assuming that the Universe has no boundaries, the first thought may be that it is the curvature of space that determines if it is finite: the surface of a sphere, for example, is unbounded yet finite. The curvature of the Universe could either be positive (hyper−spherical), negative (hyperbolic, for example saddle−shaped) or flat, but only the positive, spherical case implies that the topology is finite. The other two cases allow for both a finite and an infinite Universe.

This may seem counter−intuitive, for how can a flat unbounded Universe be finite? Luminet deals with exactly these sorts of subtleties when modelling the Universe. It turns out that all you need is the correct topological construct. Imagine tiling a plane with a repeating pattern of identical squares. Now look at all the points that make up your favourite square and require that each is identical to the corresponding point in all the other squares: the mid−points of all squares are actually "the same" point, the top edge of each square is identified to its bottom edge, and the left−hand edge to the right−hand edge. Now suppose you live in this "universe" and want to discover if it is finite. If you shine a (bright!) torch out the top of a tile, the light arrives in the tile above from below. But since this tile is identical to the one below (you exist in this tile too!), this is the same as the light arriving back in the original tile from the bottom. Light travelling through this two−dimensional universe (represented by a line across your tiling) will eventually arrive back at its starting point, having travelled a finite distance. Hence this flat unbounded Universe is finite. The tiling is just a representation of the topology of this Universe; different tiles are in fact the same (wraparound!) Universe.

Luminet proposes a similar representation of our own Universe, but with the tiling now composed of a repeating pattern of (positively curved) dodecahedrons. He introduces us to many fascinating consequences of such a Universe. Not least, the fact that, with this topology, two apparently different stars in the night sky could actually be the same star, but with the light having taken different routes to reach us. Furthermore, the actual Universe would be 120 times smaller than the equivalent hyper−spherical one. Luminet explains with great authority how these properties can be systemically tested for by current and future observations.

Luminet's dodecahedral Universe is multiply connected, which is to say you can take topologically distinct paths that arrive back at the same point. *The wraparound universe* is quite literally multiply connected: it is made up of semi−independent chapters allowing the reader to find their own path through the book. Although some readers may find this useful, particularly those who find some chapters daunting (some of the ideas, particularly the topological ones are quite subtle) others may find it frustrating; it disrupts the flow of the book, which detracts from the excellent story Luminet tells, and necessarily leads to some repetition.

Although the book serves as a good introduction to current ideas in cosmology, it is at its best when Luminet discusses his own research. The passages devoted to the evolution of his own ideas and the course of his own career are particularly engaging the book would have benefited from more space devoted to these.

The wraparound Universe should appeal to anybody with an appetite for modern cosmology. However, the ideas come thick and fast, so some basic familiarity with at least some of these concepts will add to the enjoyment.

Book details:

<u>*The wraparound universe*</u>
Jean−Pierre Luminet

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AK Peters
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About the author

Richard Allen is...

Plus is part of the family of activities in the Millennium Mathematics Project, which also includes the NRICH and MOTIVATE sites.