WHAT'S HOT IN... PHYSICS , March/April 2009

Is This the Third Revolution for String Theory?

by Simon Mitton

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Every so often the Hot Papers table of *Science Watch* captures a revolution in science. In the early 1990s buckyballs held center stage for a while, followed by light-emitting diodes. Then we had a flood of Hot Papers on high-temperature superconductivity, a field that is still with us at positions #2 and #5. Physics Hot Papers of the last ten years beautifully captured the emergence of a consensus cosmology, and the reshaping of that subject as precision science.

In the present selection, cosmology still dominates: #1 gives the latest values for several cosmological parameters, #3 describes what can be learned about dark energy by studying distant supernovae, and #8 dwells on the cosmological implications. This latest selection has an intriguing quartet of papers on string theory, describing properties of M2-branes (#4, #6, #9, and #10). Not for ten years has string theory featured this strongly. Are we seeing a revolution?

Historically, string theory is a child of the 1960s, when attempts were made to understand the strong nuclear force, which was eventually explained by quantum chromodynamics. String theory made a comeback in the 1970s-80s as a candidate for producing a unified field theory. The mid-1980s mark the first revolution in which theorists convinced themselves that five different string theories, each requiring 10 dimensions, offered a road to unification. Suddenly a curious intellectual puzzle became mainstream physics, in which vibrating strings represented elementary

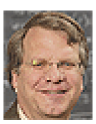
Physics Top Ten Papers

Rank	Papers	Cites Sep-Oct 08	Rank Jul-Aug 08
1	D.N. Spergel, *et al.*, "Three-year *Wilkinson Microwave Anisotropy Probe* (*WMAP*) observations: Implications for cosmology," *Astrophys. J. Suppl. Ser.*, 170(2): 377-408, June 2007. [13 U.S. and Canadian institutions] *178TD	170	1
2	X.H. Chen, *et al.*, Superconductivity at 43K in SmFeAs $O_{1-x}F_x$, *Nature*, 453 (7196): 761-2, 5 June 2008. [U. Sci. & Tech., Hefei, China] *308UK	43	†
3	A.G. Riess, *et al.*, "New *Hubble Space Telescope* discoveries of type Ia supernovae at *z* = 1: Narrowing constraints on the early behavior of dark energy," *Astrophys. J.*, 659(1): 98-121, 10 April 2007. [10 U.S. institutions] *158EF	37	4
4	J. Bagger, N. Lambert, "Gauge symmetry and supersymmetry of multiple M2-branes," *Phys. Rev. D*, 77(6): no. 065008, 15 March 2008. [Johns Hopkins U., Baltimore, MD; King's Coll. London, U.K.] *282CF	37	†

particles. The theory required that the extra 6 spatial dimensions must wrap into a tiny geometrical space, which is why we do not experience them.

The second superstring revolution dates from the mid-1990s, with the discovery of new and powerful symmetries, known as dualities. The key papers from that period show how the five apparently different string theories are all related. They are the limiting cases of an underlying theory known as M-theory, which requires 11 dimensions. Although we lack a full account of M-theory, plenty of progress has been made in understanding its properties. The fundamental objects of M-theory are membranes and higher dimensional entities collectively known as p-branes. M-theory produced the rich physics of D-branes, the objects on which the ends of open strings terminate. Mathematicians have used D-branes to probe spacetime and gauge curvature, and some have speculated that the entire visible universe is a D3-brane floating in 11 dimensions.

We can use the four Hot Papers on string theory to see if a third revolution is taking place. The high citation rates of this cluster on M2-branes suggests that it is. According to Jonathan Bagger (Johns Hopkins University) and Neil Lambert (King's College, London), "M-branes are mysterious objects, and virtually nothing is



known about their underlying dynamics" (#4), which contrasts with the D-brane scenario, where a great deal of progress has been made. Bagger-Lambert theory looks at the interactions of multiple M2-branes ending on a 5-dimensional M5 brane. The formalism is highly mathematical, and the research involves the invention of new algebra. The game involves finding a Lagrangian formulism that is consistent with the symmetries of M2-branes. In modern theoretical physics the Lagrangian is an energy density function that sums up the dynamics of the whole system, and that's why it is a starting point for investigating dynamics in M-theory. (See Research Front Map of the **"Bagger-Lambert Theory."**)

5	Z.A. Ren, *et al.*, "Superconductivity at 55 K in iron-based F-doped layered quaternary compound $Sm[O_{1-x}F_x]FeAs$," *Chinese Phys. Lett.*, 25 (6): 2215-6, June 2008. [Chinese Acad. Sci, Beijing] *306MN	36	†
6	J. Bagger, N. Lambert, "Comments on multiple M2-branes," *J. High Energy Phys.*, 2: no. 105, February 2008. [Johns Hopkins U., Baltimore; King's Coll. London, U.K.] *285GD	33	†
7	J.Y. Kim, *et al.*, "Efficient tandem polymer solar cells fabricated by all-solution processing," *Science*, 317 (5835): 222-5, 13 July 2007. [U. Calif., Santa Barbara; Gwangju Inst. Sci. Tech., Korea] *189DC	32	8
8	M. Tegmark, *et al.*, "Cosmological constraints from the SDSS luminous red galaxies," *Phys. Rev. D*, 74(12): no. 123507, December 2006. [36 institutions worldwide] *121QJ	31	3
9	P.M. Ho, Y. Imamura, Y. Matsuo, "M2 to D2 revisited," *J. High Energy Phys.*, 7: no. 003, July 2008. [Natl. Taiwan U, Taipei; U. Tokyo, Japan] *333HR	26	†
10	J. Distler, *et al.*, "M2-branes on M-folds," *J. High Energy Phys.*, 5: no. 38, May 2008. [U. Texas, Austin; Tata Inst., Mumbai, India; U. British Columbia, Vancouver, Canada] *312JA	25	†

SOURCE: Thomson Reuters *Hot Papers Database*. Read the Legend.

Hot Paper #4 develops the Bagger-Lambert field theory by first gauging the theory and then making it supersymmetric. In a companion paper, #6, they set out physical predictions for multiple M2-branes. Paper #9 makes a further advance by showing how results known for D2-branes can now be derived from Bagger-Lambert theory. Finally #10 explores a new class of algebraic puzzles that M-theory has uncovered.

This *Science Watch* compilation shows that the string-theory circus is back in town with a whole new show, but physicists on the sidewalk continue to be deeply skeptical, questioning whether these mathematical conjuring tricks involve physics at all. On the positive side, the history of physics teaches us that the greatest breakthroughs required an enormous prior effort to develop new mathematical tools. Thus it was that Newton invented calculus, Maxwell introduced vector algebra, while Einstein adopted 4-dimensional geometry and tensor algebra. For Newtonian mechanics and general relativity, initially only a few practitioners could get their heads around the math. Just like today, really.

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