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WHAT'S HOT IN... PHYSICS , January/February 2009

Precision Cosmology Soars to New Heights

by Simon Mitton

PDF

Half of the papers in the Physics Top Ten, #1, #2, #3, #4, and #7, capture one of the greatest events in the entire history of cosmology. In the past ten years, attempts to understand the nature of the universe have progressed from a handful of numbers, some with significant error bars, to a truly precision science that now places strong boundary conditions on cosmological models: parameter space for modelling freely is getting much smaller, and the misfits are being thrown out. How has this been achieved? Two keys have unlocked a vast vault of cosmic secrets.

First, NASA's Cosmic Background Explorer (COBE), launched in 1989, quickly produced a spectacular result: the cosmic background (CMB) has a thermal temperature of 2.725 K. This result confirmed the "hot big bang" paradigm. Subsequently, COBE data revealed exquisite structure in the CMB, structure that had been imprinted shortly after the big bang. For these discoveries, John C. Mather and George Smoot won the Nobel Prize in Physics in 2006. In a public statement, the Nobel Committee said "the COBE project can also be regarded as the starting point for cosmology as a precision science."

The development of supernova cosmology provided the second key some ten years ago when it became clear that Type 1a supernovae could be used as accurate standard candles to map the universe out to a redshift z = 1. The application of these supernovae to observational cosmology led a surprise: the expansion of the universe is

Physics Top Ten Papers

Rank	Papers	Cites Jul-Aug 08	Rank May-Jun 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	217	1
2	G. Hinshaw, *et al.*, "Three-year *Wilkinson Microwave Anisotropy Probe* (*WMAP*) observations: Temperature analysis," *Astrophys. J. Suppl. Ser.*, 170(2): 288-334, June 2007. [14 U.S. and Canadian institutions] *178TD	46	5
3	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	39	7
4	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	36	†
5	M.Y Han, *et al.*, "Energy band-gap engineering of graphene nanoribbons," *Phys. Rev. Lett.*, 98(20): no. 206805, 18 May 2007. [Columbia U., New York, NY] *169WY	34	†

accelerating.

With these two key stages, the so-called Lambda-Cold Dark Matter (?CDM) model of the universe took off, thanks to its ability to account for the accelerating universe (the lambda term) and the large-scale structure properties associated with the CMB.

Hot Paper #1 showcases the third-year results from the Wilkinson Microwave Anisotropy Probe. *Science Watch* has already given full coverage of the first-year data which fits the ?CDM model. In this scheme the universe is flat, homogeneous, and isotropic; composed of baryonic matter, radiation, and dark matter; and has a cosmological constant ? driving the acceleration. Considered as dark energy, the ? term weights in with 73% of the energy density of the universe

What the related paper #2 is all about is the extent to which three years of data acquisition, reduction, and refinement have significantly improved knowledge of the cosmological constants. Opportunity is taken in #1 to relate the three-year results from those for the Sloan Digital Sky Survey (SDSS, subject of #3 and #7), small-scale CMB data from ground-based groups, and much larger samples of high-z supernovae (subject of #4). Errors on the WMAP data are now 3 times smaller, and yet the ?CDM model continues to thrive. There is little room for significant changes to the basic model.

6	T. Ohta, *et al.*, "Controlling the electronic structure of bilayer graphene," *Science*, 313(5789): 951-4, 18 August 2006. [Lawrence Berkeley Natl. Lab., Berkeley, CA; Fritz Haber Institute, Berlin, Germany; U. Erlangen-Nurnberg, Germany] *074MR	32	†
7	J.K. Adelman-McCarthy, *et al.*, "The fifth data release of the Sloan Digital Sky Survey," *Astrophys. J. Suppl. Ser.*, 172 (2): 634-44, October 2007. [73 institutions worldwide] *212HY	30	†
8	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	28	9
9	S.Y. Zhou, *et al.*, "Substrate-induced bandgap opening in epitaxial graphene," *Nature Mater.*, 6(10): 770-5, October 2007. [5 U.S. and Spanish institutions] *216GO	26	†
10	J. Kasprzak, *et al.*, " Bose-Einstein condensation of exciton polaritons," *Nature*, 443 (7110): 409-14, 28 September 2006. [5 institutions worldwide] *088FY	25	†

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

Paper #4, from Adam Riess (Johns Hopkins University, Baltimore) and colleagues, reveals remarkable news from the Hubble Space Telescope concerning 21 z = 1 Type 1a supernovae. These beacons push the look-back time to 10 Gyr (gigayears), and provide a factor of 2 improvement to constrain the equation of state for dark energy. That's important because the CMB results have left astronomers in the dark about how dark energy should be factored in beyond z = 1.8. Rapidly evolving dark energy is ruled out, and negative pressure, a defining characteristic of dark energy, appears to be present at z = 1, which is before the epoch of acceleration. In fact, Riess *et al.* now strengthen their claim that a cosmic jerk, some 5 Gyr ago, snapped the universe out of deceleration under gravity, and propelled into the present inflationary phase. Although Riess first made these claims in 2003, there was always a nagging doubt about their authenticity. The latest result pushes the frontier of exploration a further 5 Gyr beyond the tipping point at 5 Gyr.

Finally, #7 announces the fifth data release of the SDSS, which now encompasses spectra and photometric data for10^6 galaxies and 10^5 quasars. The high citation rate reflects the huge value of this database for cosmological studies: more than 1,000 papers have cited the successive SDSS releases.

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Keywords: cosmology, COBE, Cosmic Microwave Background Explorer, cosmic microwave background, CMB, supernovae, Adam Riess, Wilkinson Microwave Anisotropy Probe, Sloan Digital Sky Survey, SDSS.

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