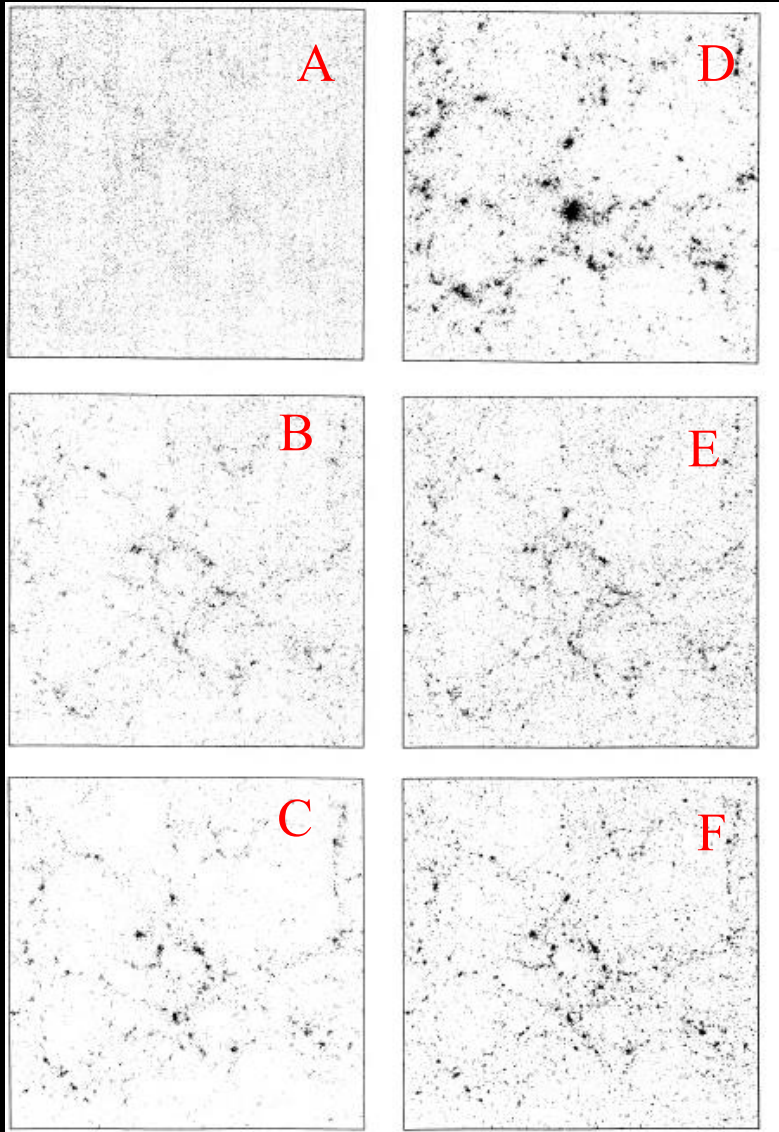


THE EVOLUTION OF LARGE-SCALE STRUCTURE IN A UNIVERSE DOMINATED BY COLD  
DARK MATTER

MARC DAVIS,<sup>1,2</sup> GEORGE EFSTATHIOU,<sup>1,3</sup> CARLOS S. FRENK,<sup>1,4</sup> AND SIMON D. M. WHITE<sup>1,5</sup>

*Received 1984 August 20; accepted 1984 November 30*



A-D are a time sequence in an  $\Omega_m=1$  model.

E, F are a time sequence in an  $\Omega_m=0.2$  model.

# A CASE STUDY OF LARGE-SCALE STRUCTURE IN A "HOT" MODEL UNIVERSE

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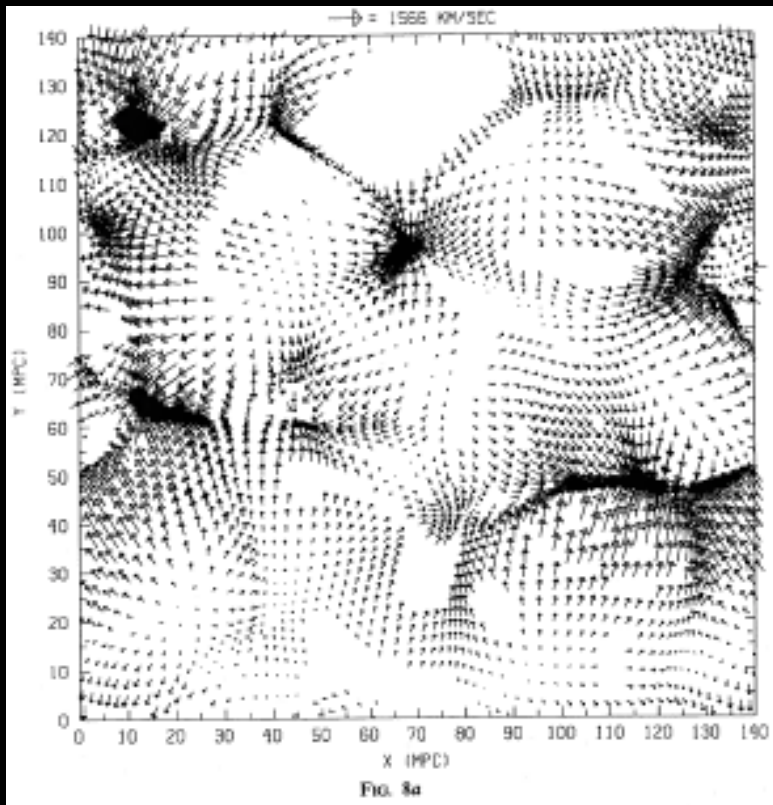


FIG. 8a

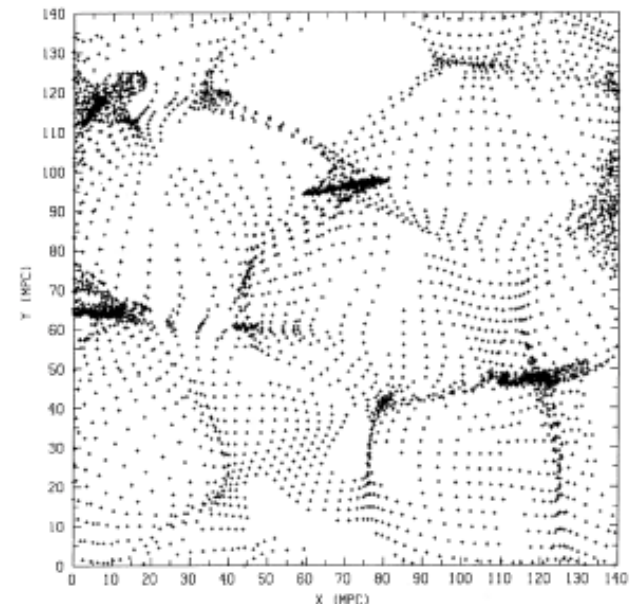


FIG. 7a

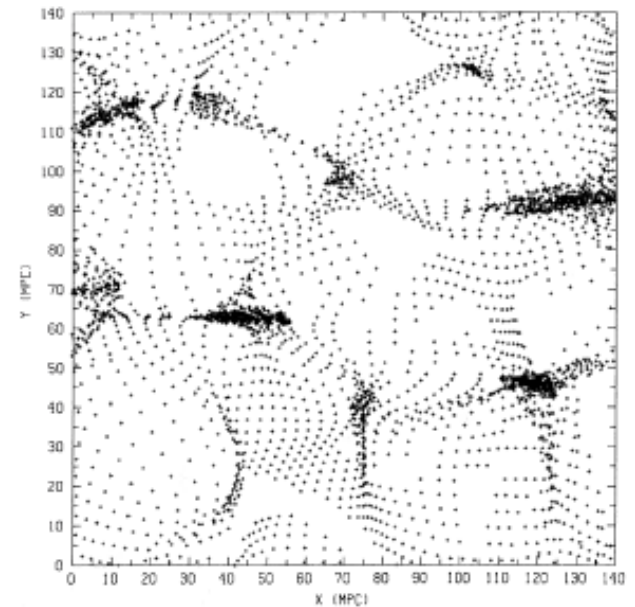
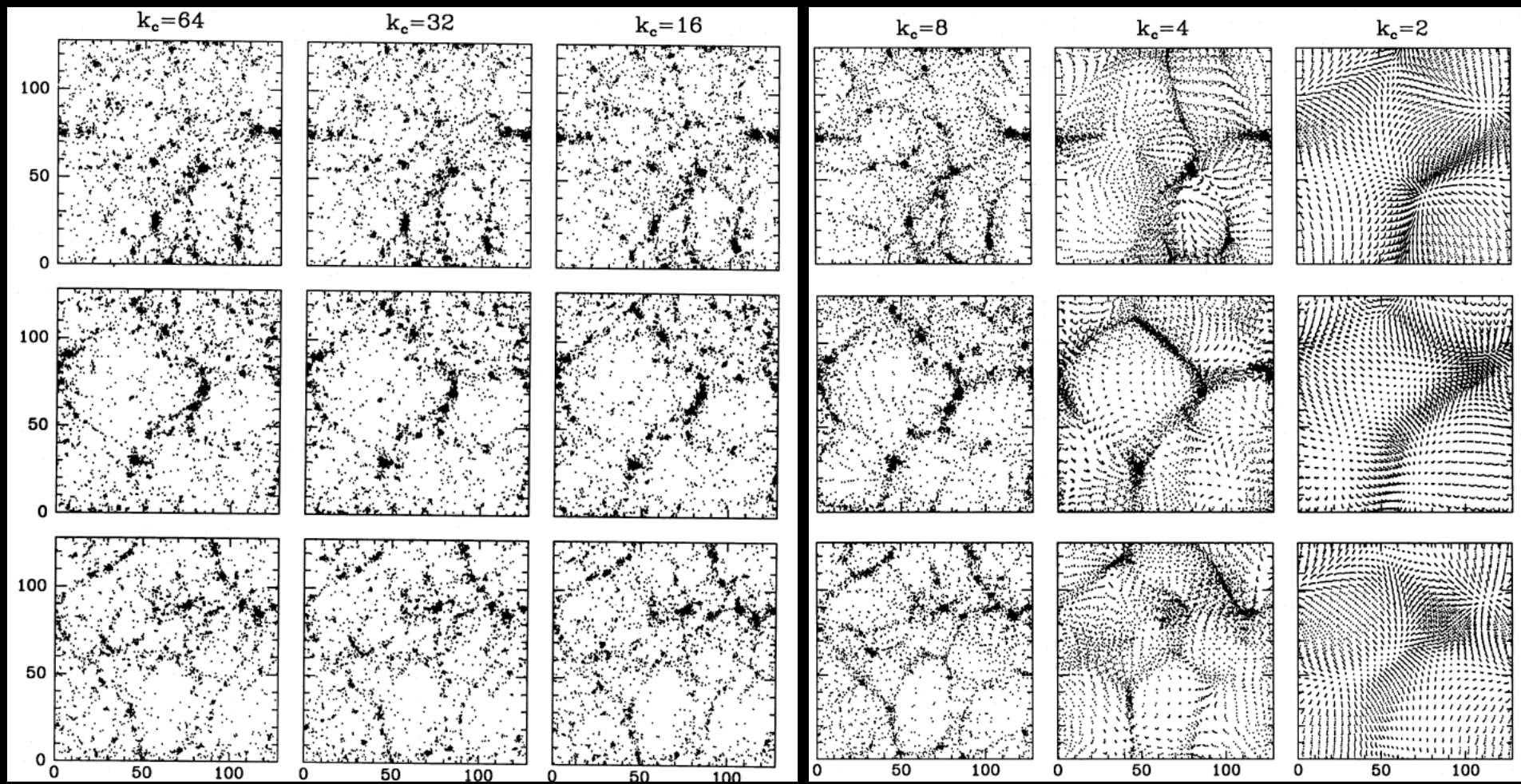


FIG. 7b

# Primordial fluctuations and non-linear structure

Blane Little,<sup>1</sup> David H. Weinberg<sup>1,2</sup> and Changbom Park<sup>3,4</sup>



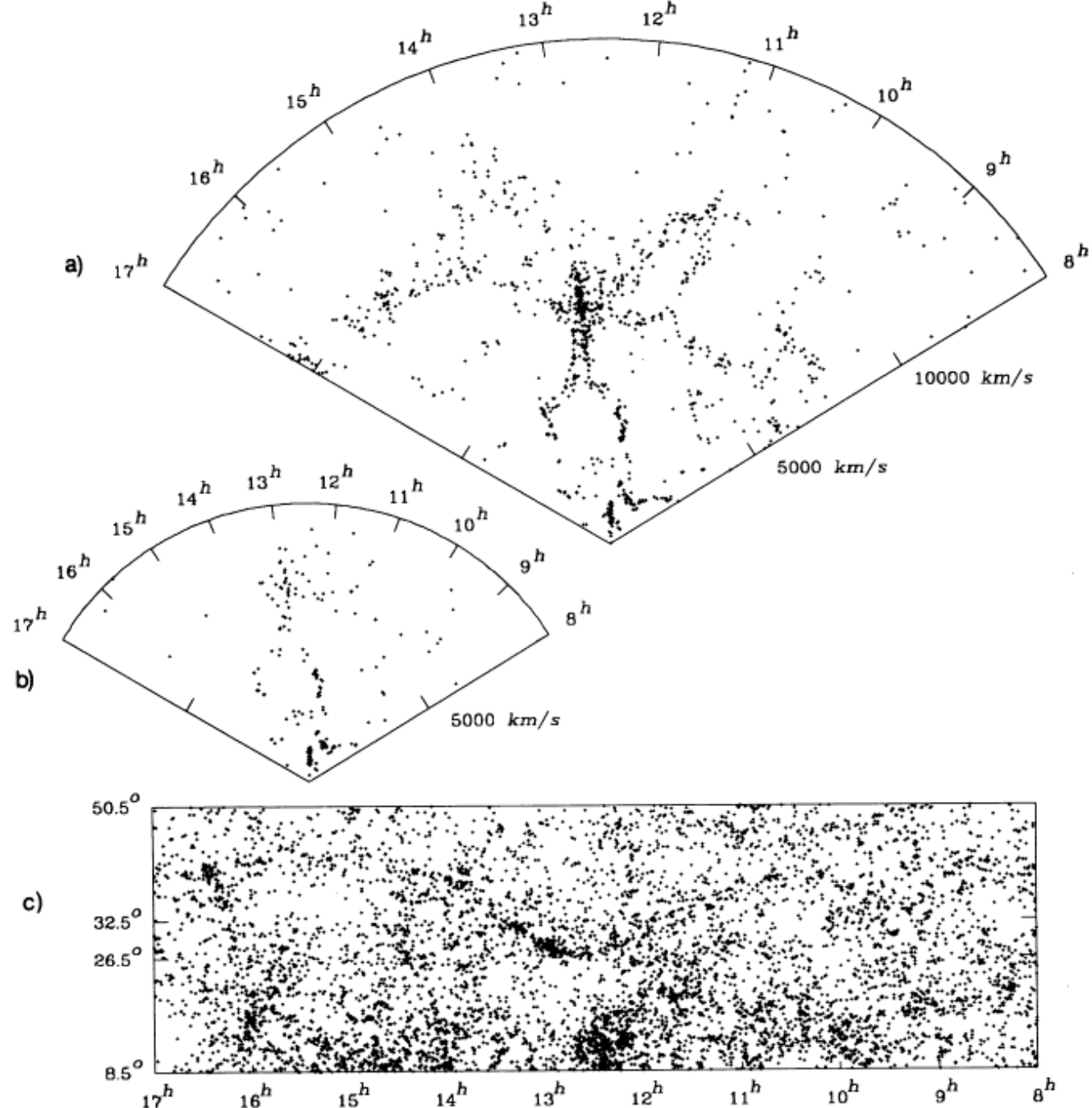


FIG. 1.—(a) Map of the observed velocity plotted vs. right ascension in the declination wedge  $26.5^\circ \leq \delta \leq 32.5^\circ$ . The 1061 objects plotted have  $m_B \leq 15.5$  and  $V \leq 15,000 \text{ km s}^{-1}$ . (b) Same as Fig. 1a for  $m_B \leq 14.5$  and  $V \leq 10,000 \text{ km s}^{-1}$ . The plot contains 182 galaxies. (c) Projected map of the 7031 objects with  $m_B \leq 15.5$ , listed by Zwicky *et al.* in the region bounded by  $8^h \leq \alpha \leq 17^h$  and  $8.5^\circ \leq \delta \leq 50.5^\circ$ .

CLUSTERS, FILAMENTS, AND VOIDS IN A UNIVERSE DOMINATED  
BY COLD DARK MATTER

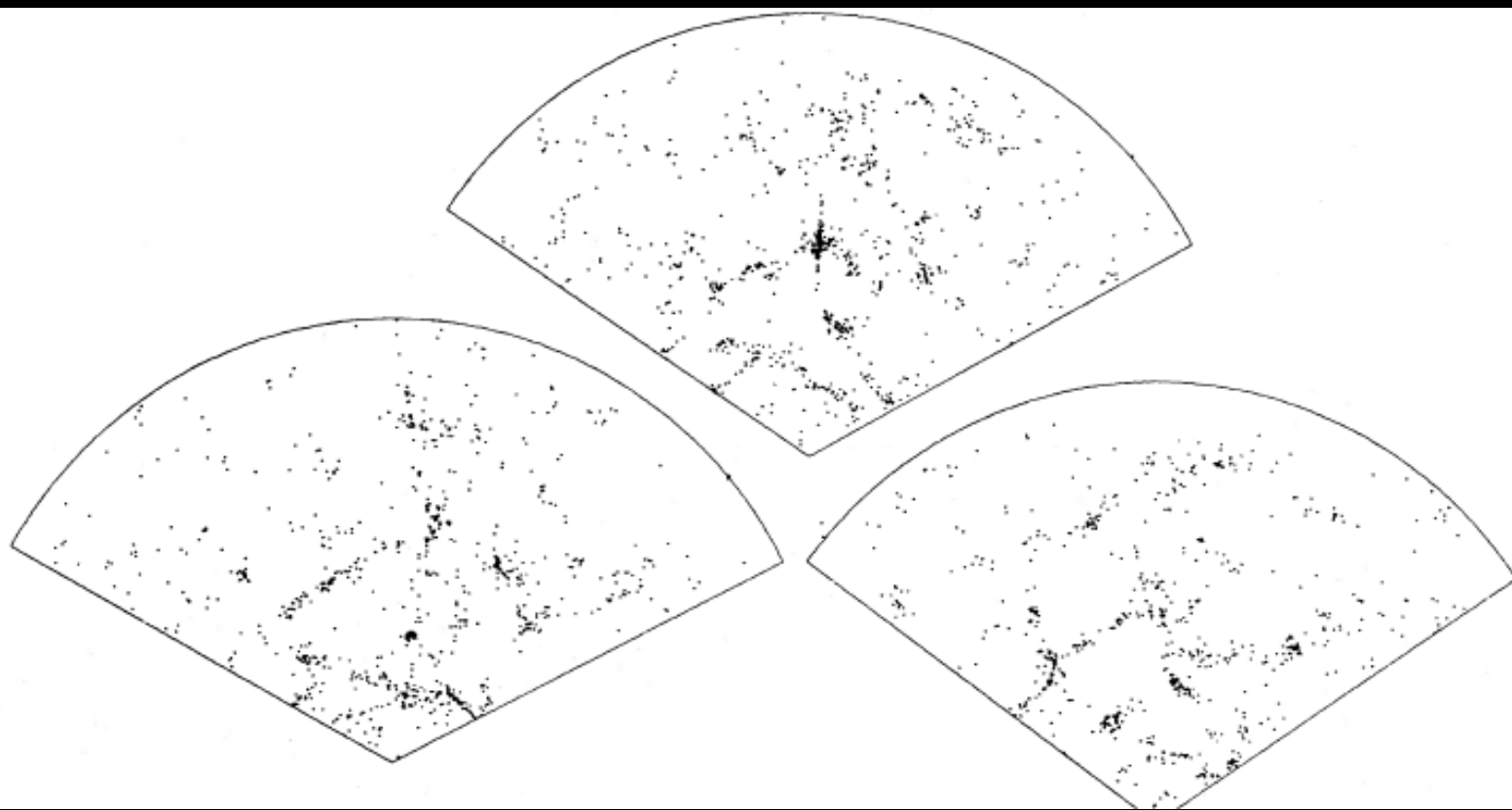
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Steward Observatory, University of Arizona

CARLOS S. FRENK  
Physics Department, University of Durham

MARC DAVIS  
Astronomy Department, University of California, Berkeley

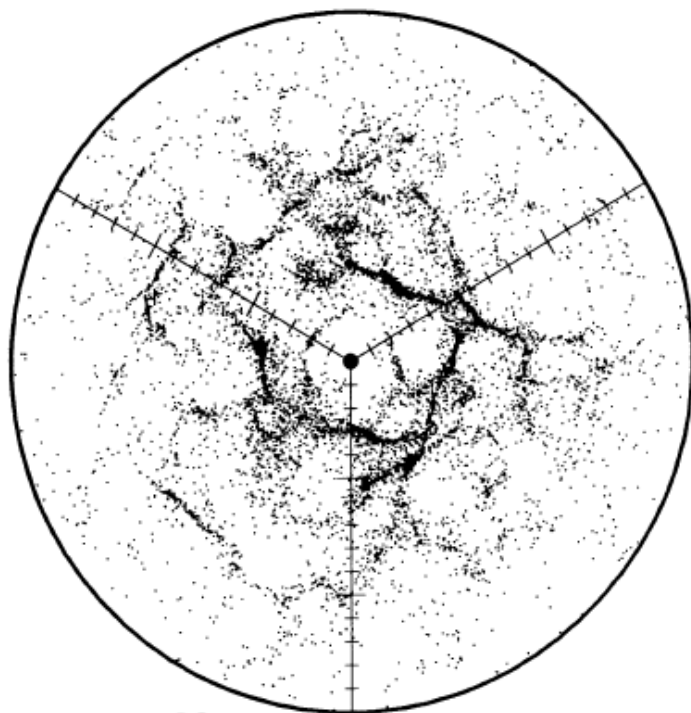
AND

GEORGE EFSTATHIOU  
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*Received 1986 July 1; accepted 1986 August 6*

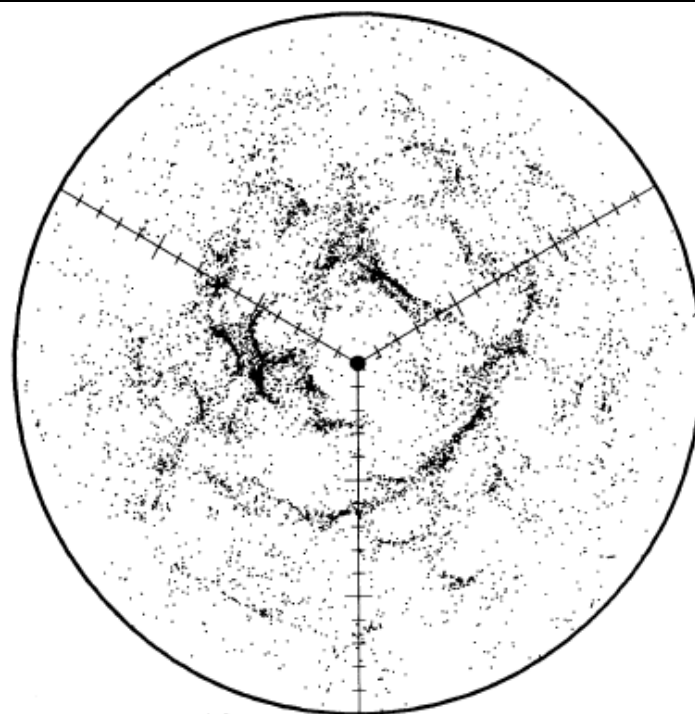


# SIMULATIONS OF DEEP REDSHIFT SURVEYS

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Department of Astrophysical Sciences, Princeton University  
*Received 1989 July 10; accepted 1990 January 12*



$0 < \delta < 20$   
 $m < 15.5$   
10258 galaxies



$20 < \delta < 40$   
 $m < 15.5$   
7712 galaxies

STATISTICAL ANALYSIS OF CATALOGS OF EXTRAGALACTIC OBJECTS.  
III. THE SHANE-WIRTANEN AND ZWICKY CATALOGS\*

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Joseph Henry Laboratories, Physics Department, Princeton University

AND

M. G. HAUSER

Physics Department, California Institute of Technology

Received 1973 July 16

ABSTRACT

We present a statistical investigation of clustering in the galaxy catalogs compiled by Zwicky *et al.* and by Shane and Wirtanen. We estimate the covariance and power spectrum of the angular distributions. We find that the region of space surveyed in the Zwicky Catalog acts like a "fair sample of the Universe," in the sense that the statistical nature of the clustering revealed by this catalog is found mirrored at smaller angular scales in the deeper survey of Shane and Wirtanen. We find that the spatial correlation of galaxies as mapped in these surveys is quite small for separations greater than about  $20h^{-1}$  Mpc ( $h$  = Hubble's constant in units of  $100 \text{ km s}^{-1} \text{ Mpc}^{-1}$ ). Although this estimate is uncertain because of the uncertainty in the galaxy luminosity function, the correlation length for galaxies seems to fall clearly below the corresponding quantity for the distribution of the rich clusters of galaxies.

*Subject headings:* galaxies, clusters of

STATISTICAL ANALYSIS OF CATALOGS OF EXTRAGALACTIC OBJECTS. VII.  
TWO- AND THREE-POINT CORRELATION FUNCTIONS FOR THE HIGH-  
RESOLUTION SHANE-WIRTANEN CATALOG OF GALAXIES\*

EDWARD J. GROTH AND P. J. E. PEEBLES

Joseph Henry Laboratories, Physics Department, Princeton University

Received 1977 March 4; accepted 1977 April 7

ABSTRACT

We present estimates of the two- and three-point angular correlation functions for the high-resolution ( $10'$ ) Shane-Wirtanen catalog of galaxies. Special attention is given to statistical corrections for plate-to-plate variations of limiting magnitude, counting error, and the effect of the  $10' \times 10'$  counting cell. The two-point function is well approximated by a power law for  $\theta \lesssim 2.5$ , corresponding to a projected distance of  $\sim 9h^{-1}$  Mpc ( $H = 100h \text{ km s}^{-1} \text{ Mpc}^{-1}$ ), but breaks sharply below the power law at larger angles. Several arguments indicate that the break is an intrinsic feature of the galaxy distribution, not an artifact of the analysis. New scaling relations taking account of redshift and curvature are derived and used to compare the correlation functions estimated for the Zwicky, Shane-Wirtanen, and Jagellonian samples. Corrections for redshift effects are about 20% for scaling between the Zwicky and Shane-Wirtanen catalogs, and including them improves the agreement among the estimates. The two-point spatial function is estimated to be  $\xi(r) = (r_0/r)^{1.77}$ , with  $r_0 = 4.7h^{-1}$  Mpc,  $0.05 \text{ Mpc} \leq hr \leq 9 \text{ Mpc}$ . The three-point function at  $\theta \lesssim 3^\circ$  is well represented by the model  $\xi(1, 2, 3) = Q[\xi(1)\xi(2) + \xi(2)\xi(3) + \xi(3)\xi(1)]$  for the spatial function, with  $Q = 1.29 \pm 0.21$ . The three-point function shows little or no evidence of a preference for linear features in the galaxy distribution.

*Subject headings:* galaxies: clusters of

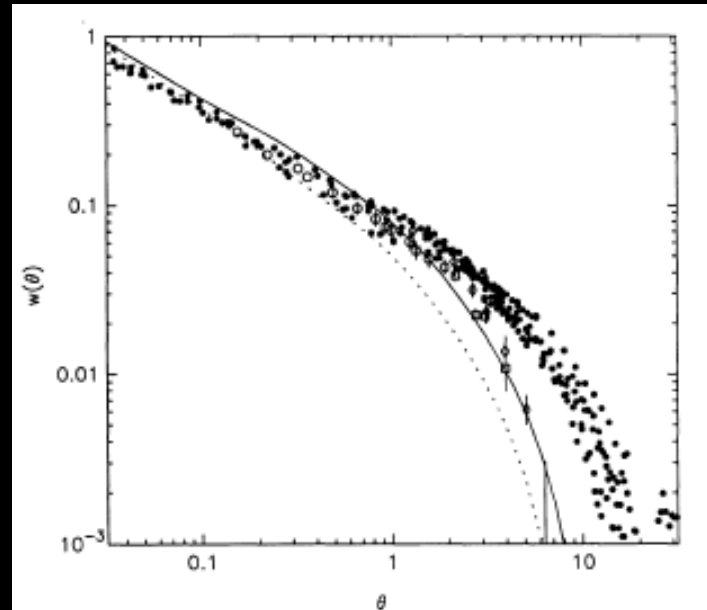
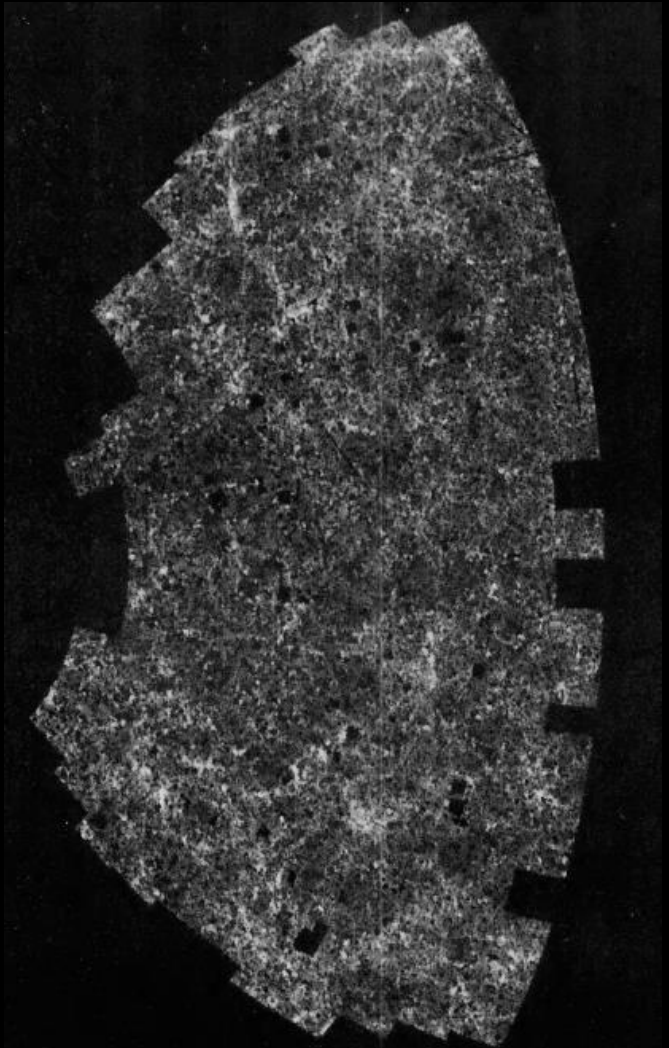
Shane & Wirtanen 1954

## Galaxy correlations on large scales

S. J. Maddox,<sup>1</sup> G. Efstathiou,<sup>1</sup> W. J. Sutherland<sup>1,2</sup> and J. Loveday<sup>1,2</sup>

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APM angular correlation vs. linear CDM prediction with  $\Omega_m=1$  and  $h=0.5$  (dotted) or 0.4 (solid). “Excess large scale power.”

# The cosmological constant and cold dark matter

G. Efstathiou, W. J. Sutherland & S. J. Maddox

Department of Physics, University of Oxford, Oxford OX1 3RH, UK

THE cold dark matter (CDM) model<sup>1-4</sup> for the formation and distribution of galaxies in a universe with exactly the critical density is theoretically appealing and has proved to be durable, but recent work<sup>5-8</sup> suggests that there is more cosmological structure on very large scales ( $l > 10 h^{-1}$  Mpc, where  $h$  is the Hubble constant  $H_0$  in units of  $100 \text{ km s}^{-1} \text{ Mpc}^{-1}$ ) than simple versions of the CDM theory predict. We argue here that the successes of the CDM theory can be retained and the new observations accommodated in a spatially flat cosmology in which as much as 80% of the critical density is provided by a positive cosmological constant, which is dynamically equivalent to endowing the vacuum with a non-zero energy density. In such a universe, expansion was dominated by CDM until a recent epoch, but is now governed by the cosmological constant. As well as explaining large-scale structure, a cosmological constant can account for the lack of fluctuations in the microwave background and the large number of certain kinds of object found at high redshift.

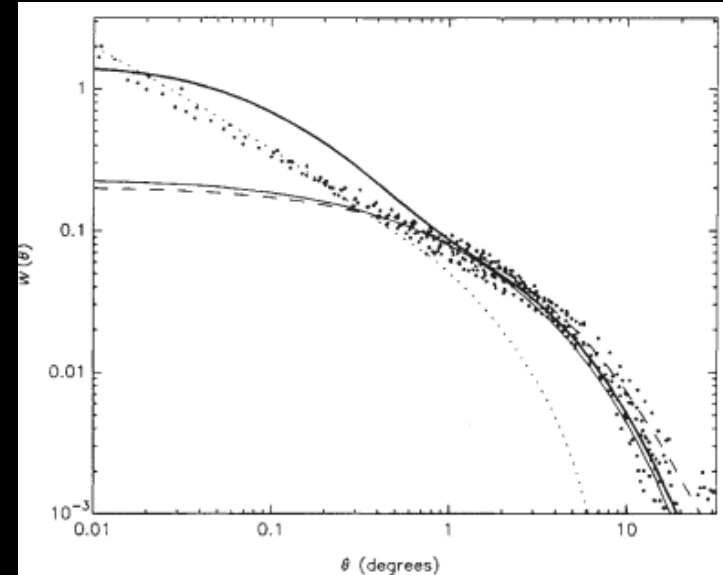
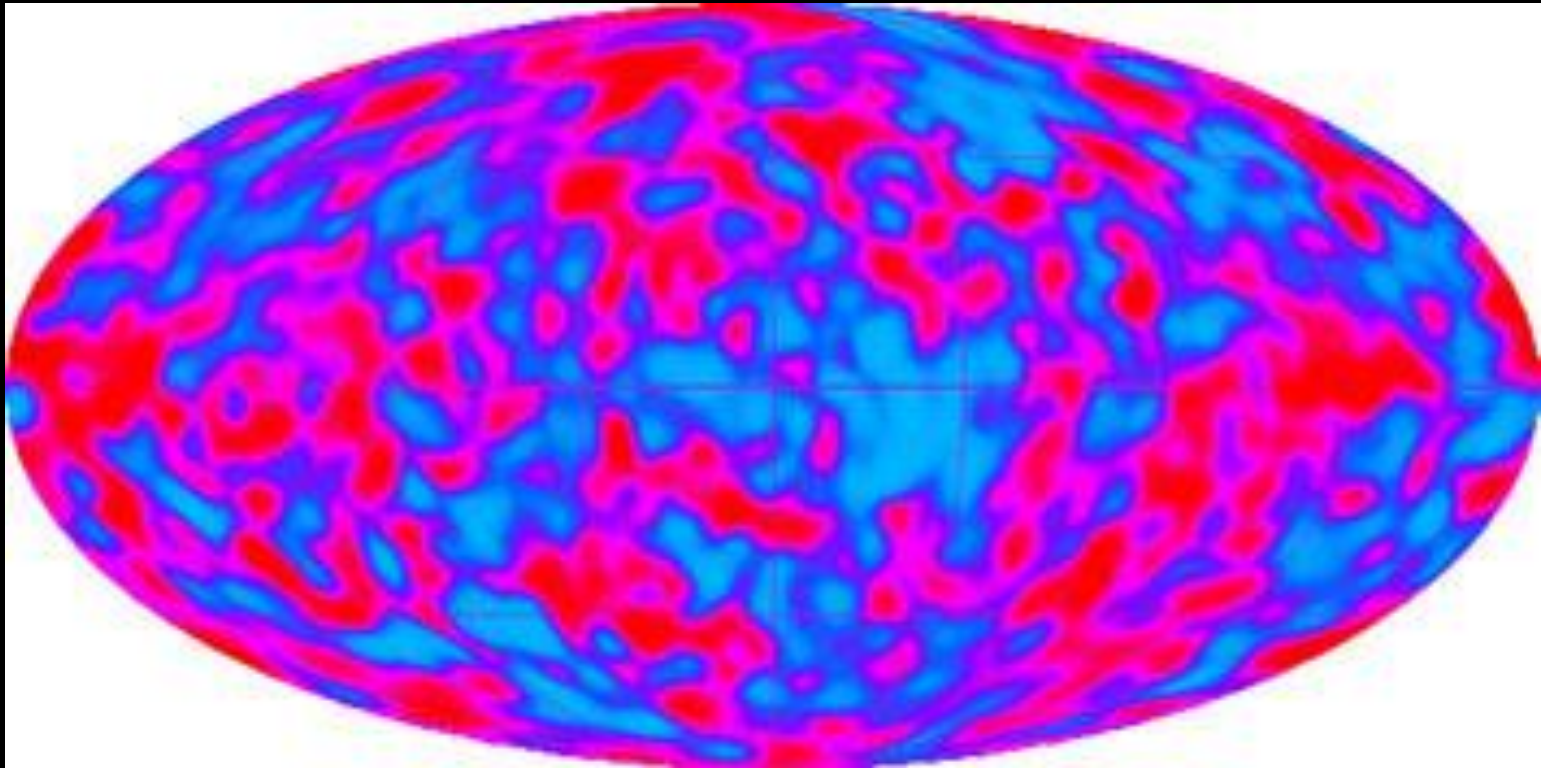


FIG. 1 The dots show estimates of the angular correlation function  $w(\theta)$  for galaxies in the APM galaxy survey (see ref. 5 for details). These estimates have been scaled to the depth of the Lick galaxy catalogue where  $1^\circ$  corresponds to a spatial scale of  $\sim 5h^{-1}$  Mpc. The dotted line shows the predictions of the  $\Omega=1$  CDM model (from ref. 5). The thin solid and dashed lines show the results of the linear theory for  $\Omega_0=0.2$  scale-invariant CDM models with  $h=1$  and  $0.75$ , respectively. The thick solid line shows  $N$ -body results for  $\Omega=0.2$  and  $h=0.9$ ; the flattening of this curve at angular scales  $\leq 0.1^\circ$  is an artefact of the resolution of the computer code, but the excess between  $0.1^\circ$  and  $1^\circ$  is real (see Fig. 2).

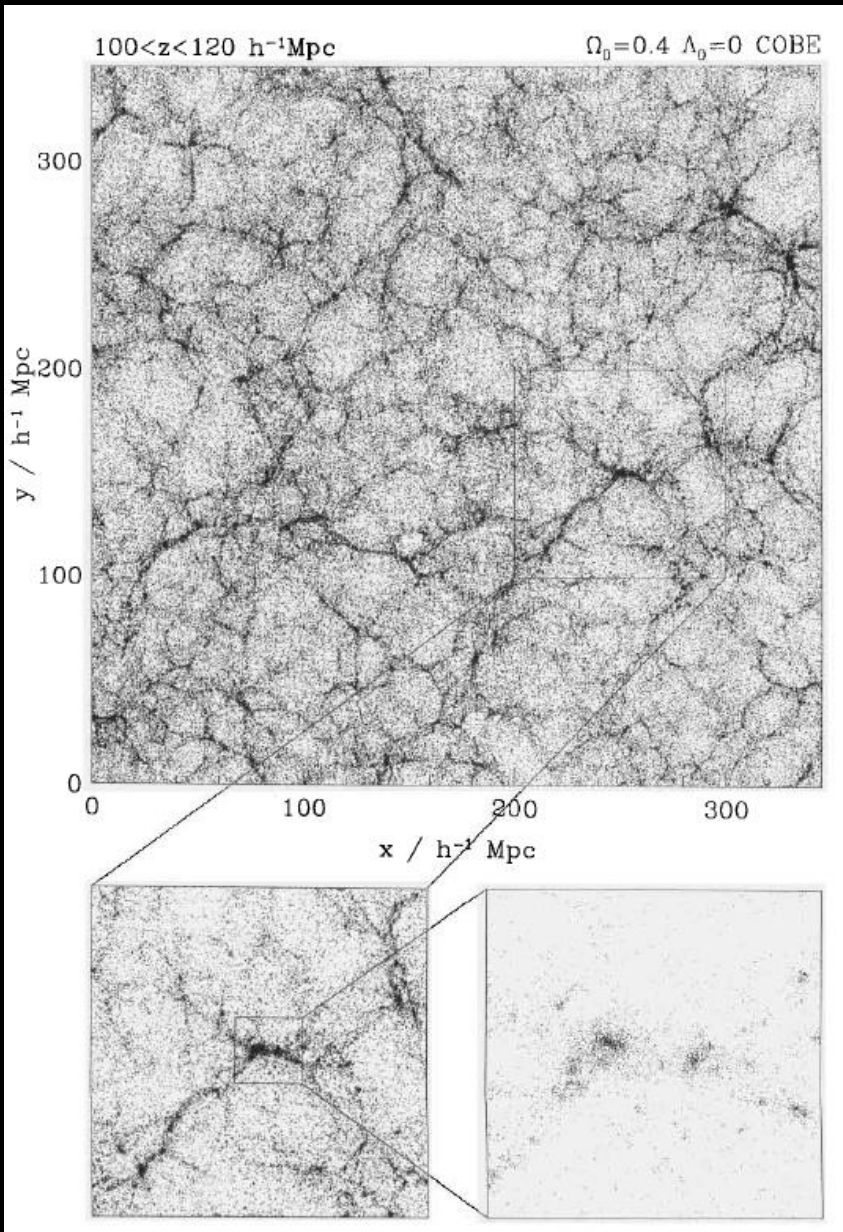


Cosmic Background Explorer (COBE), 1992++

# Large-scale structure in *COBE*-normalized cold dark matter cosmogonies

Shaun Cole,<sup>1</sup> David H. Weinberg,<sup>2</sup> Carlos S. Frenk<sup>1</sup> and Bharat Ratra<sup>3\*</sup>

1997



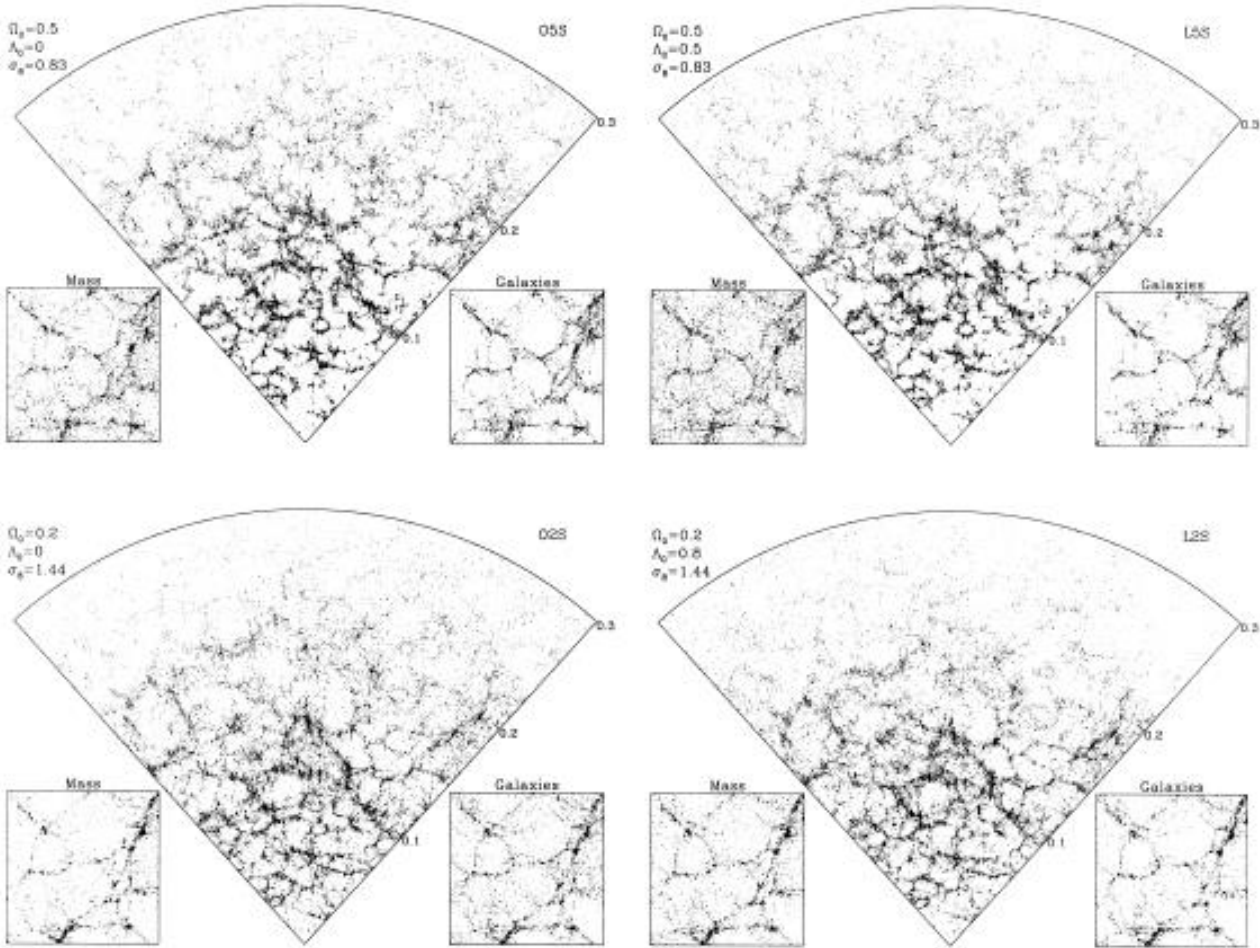
# Mock 2dF and SDSS galaxy redshift surveys

Shaun Cole,<sup>1\*</sup> Steve Hatton,<sup>1\*</sup> David H. Weinberg<sup>2\*</sup> and Carlos S. Frenk<sup>1\*</sup>

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Accepted 1998 June 22. Received 1998 June 8; in original form 1998 January 26



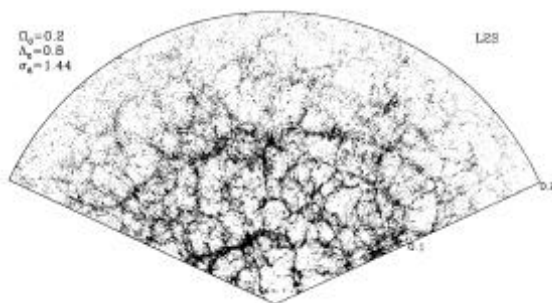
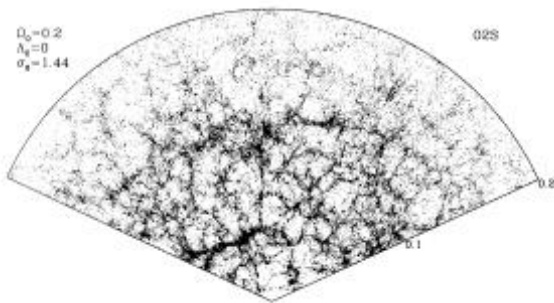
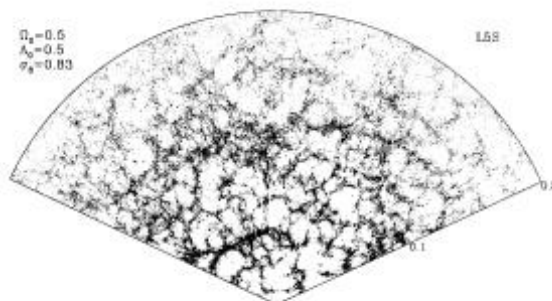
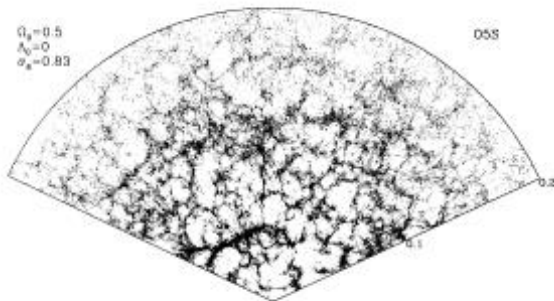
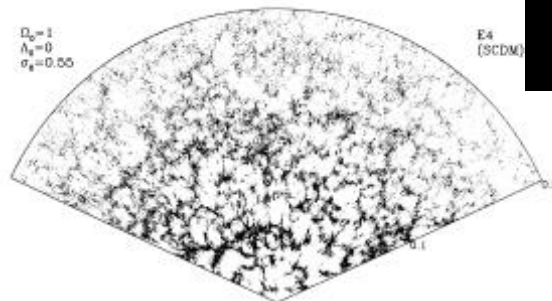
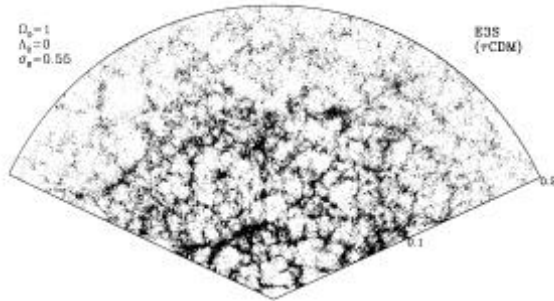
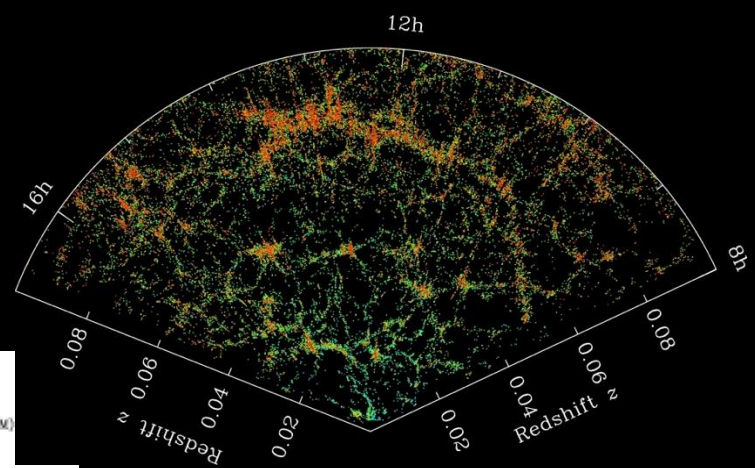
# Mock 2dF and SDSS galaxy redshift surveys

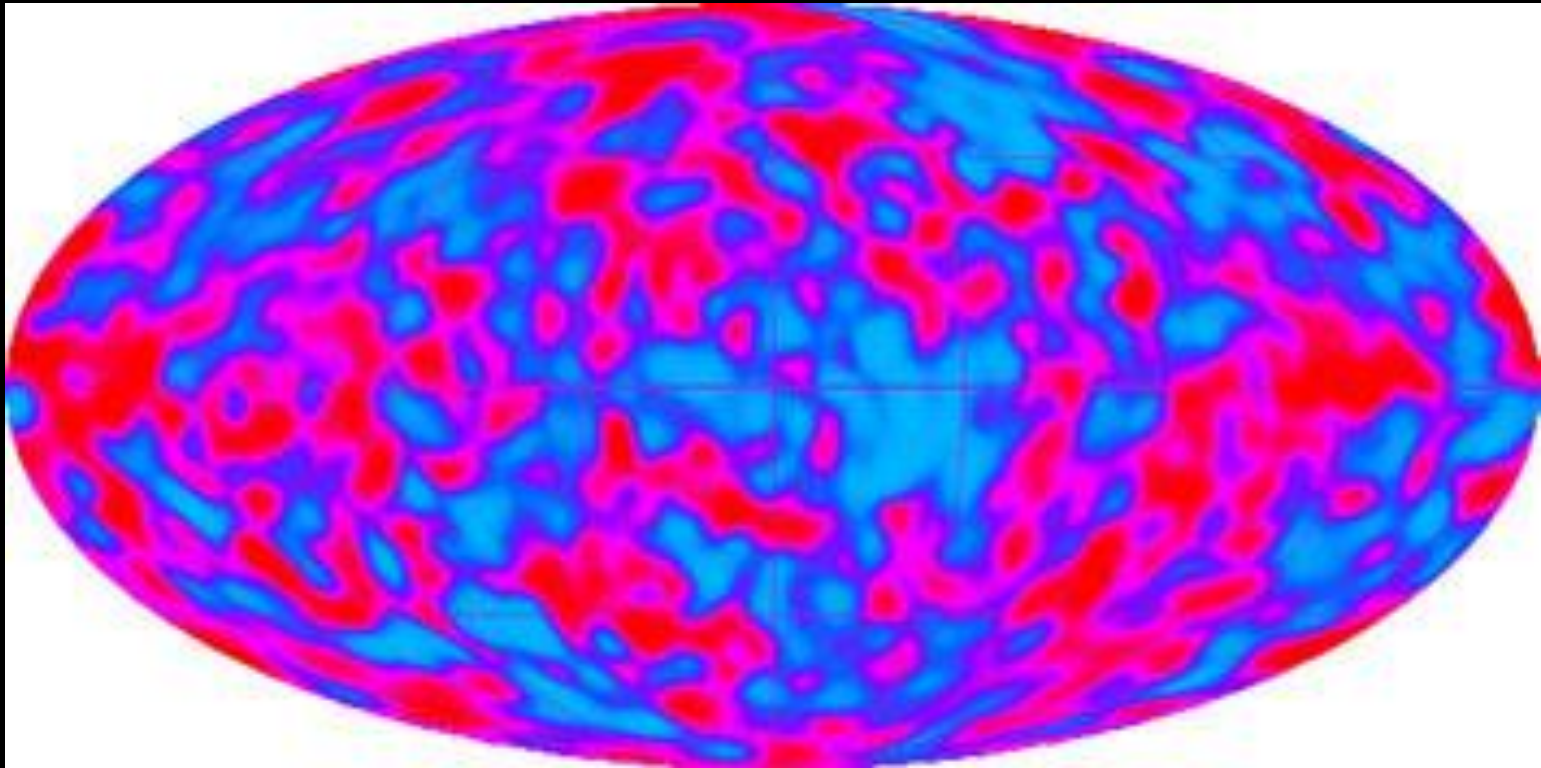
Shaun Cole,<sup>1\*</sup> Steve Hatton,<sup>1\*</sup> David H. Weinberg<sup>2\*</sup> and Carlos S. Frenk<sup>1\*</sup>

<sup>1</sup>*Department of Physics, University of Durham, Science Laboratories, South Road, Durham DH1 3LE*

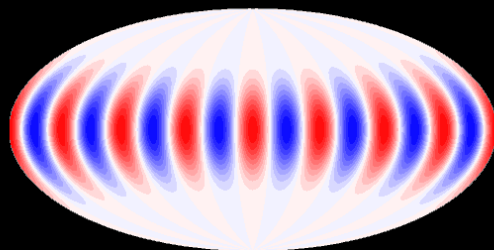
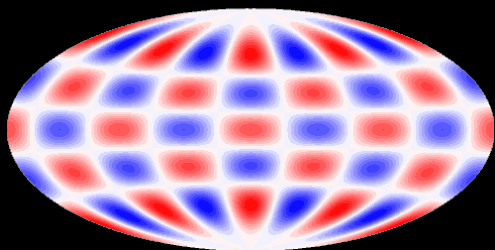
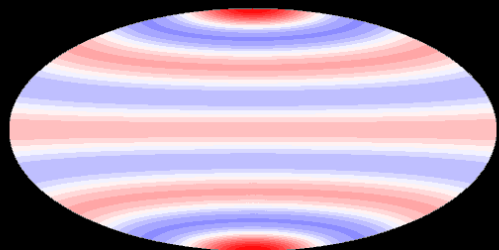
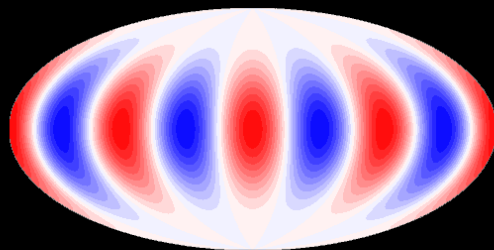
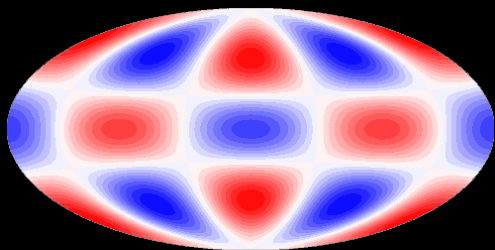
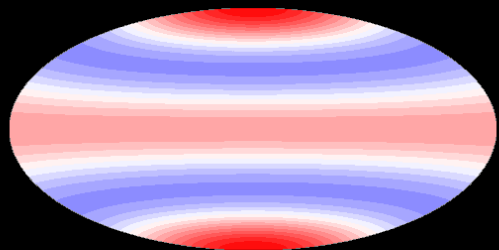
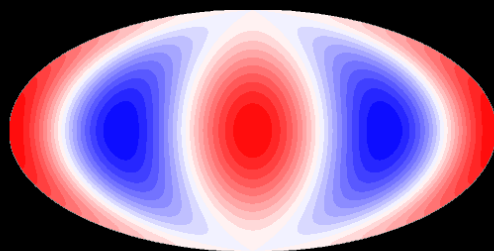
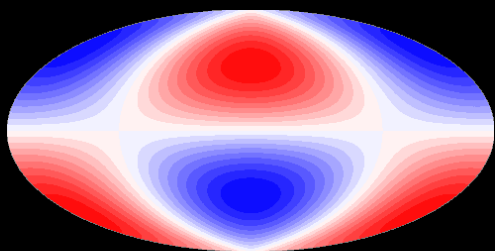
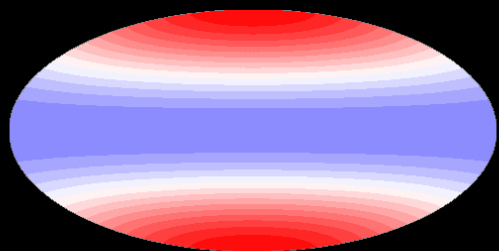
<sup>2</sup>*Department of Astronomy, Ohio State University, 174 W. 18th Avenue, Columbus, OH 43210, USA*

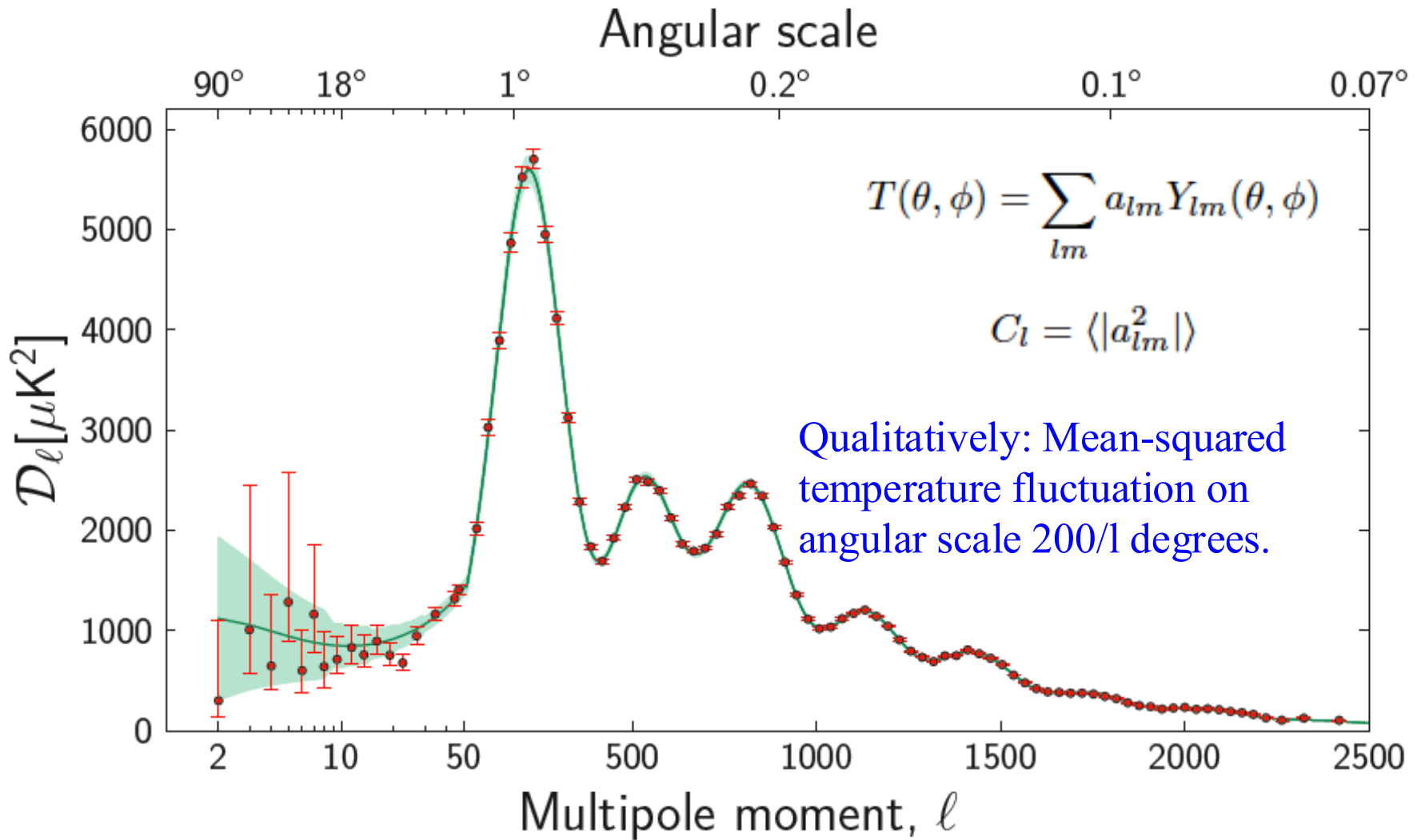
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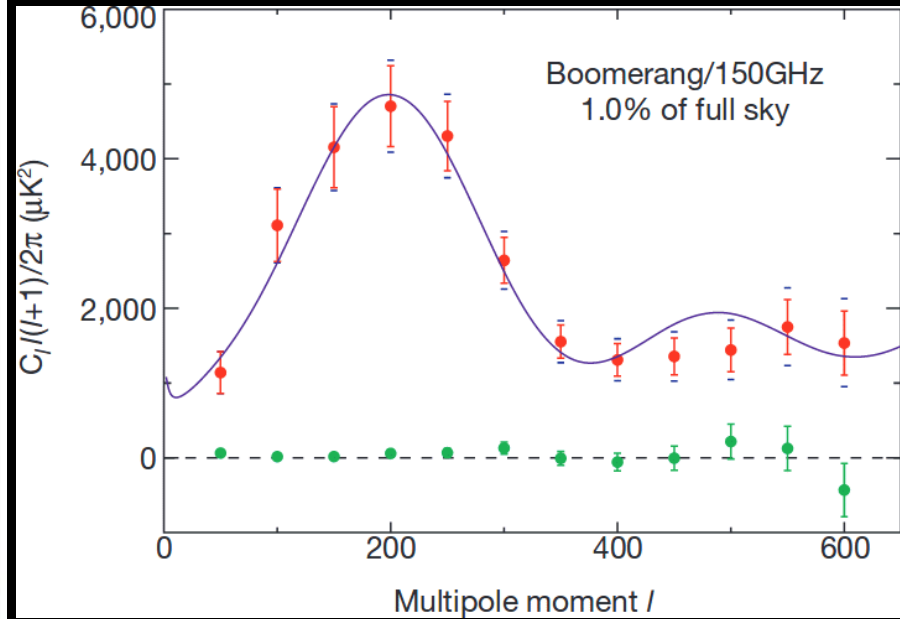
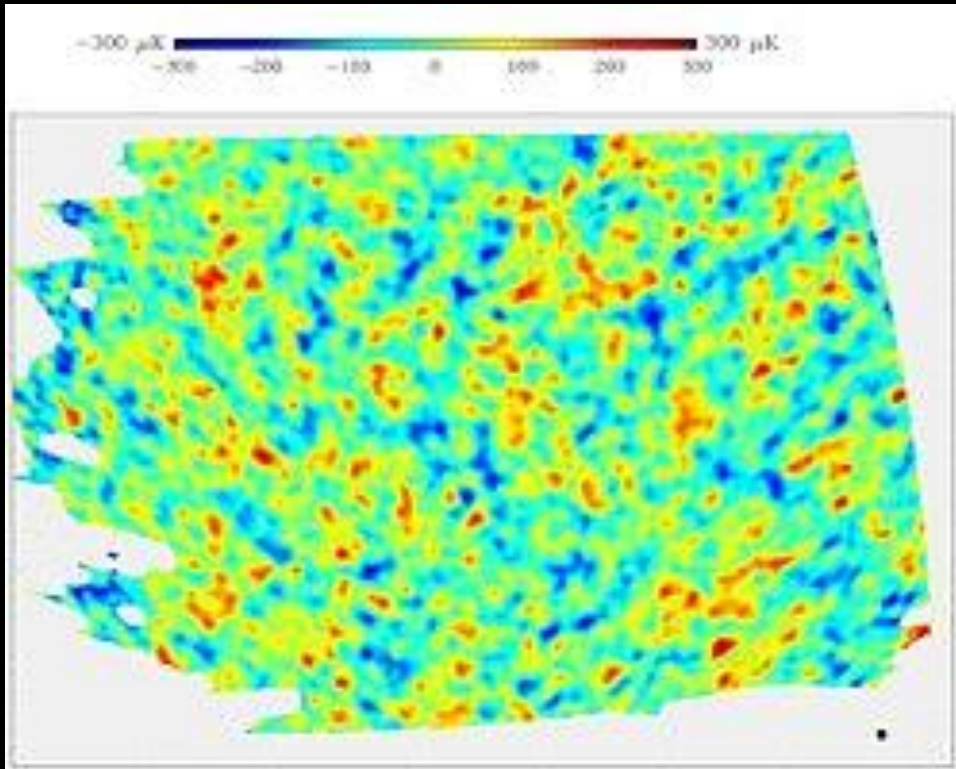




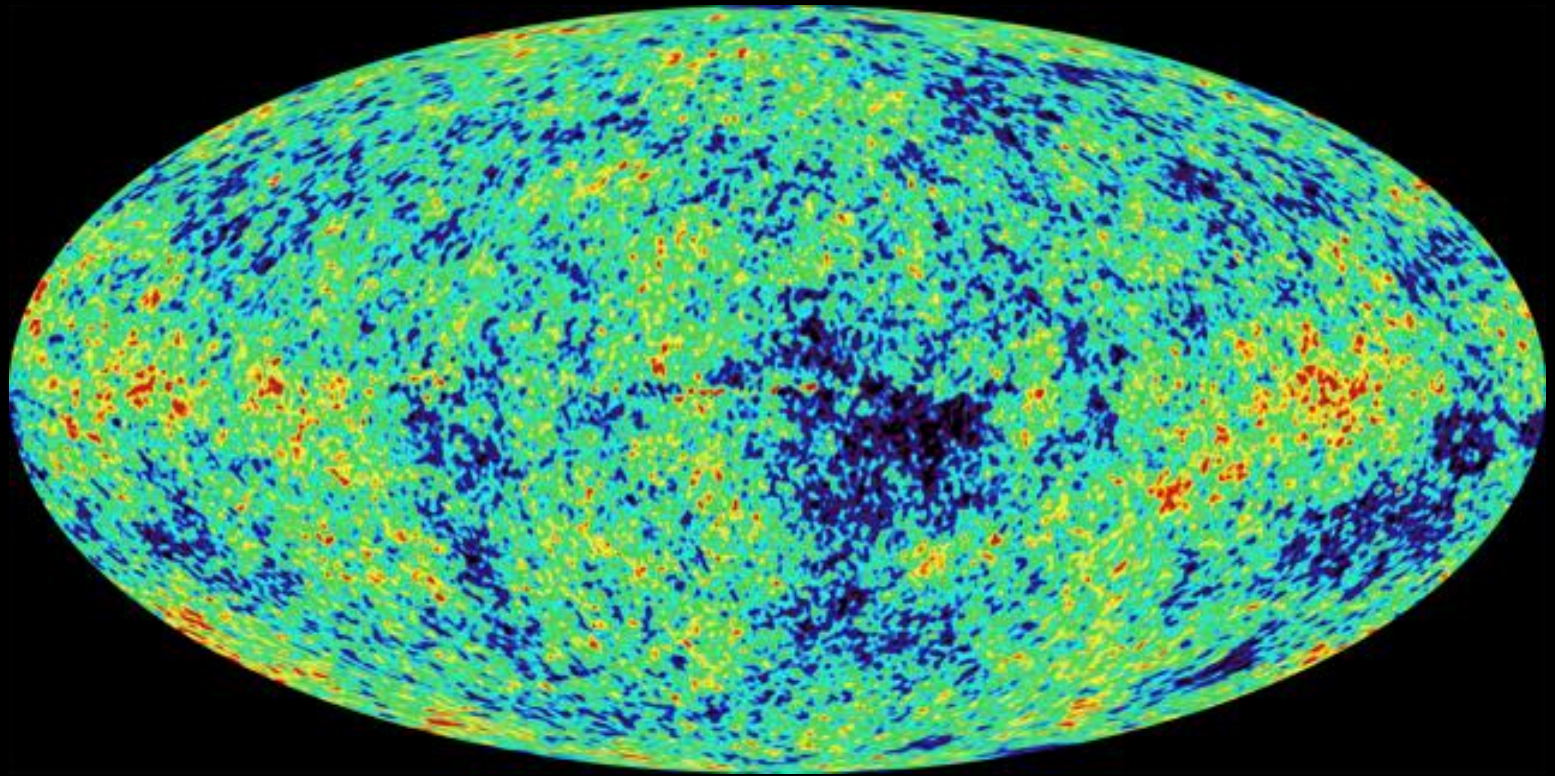
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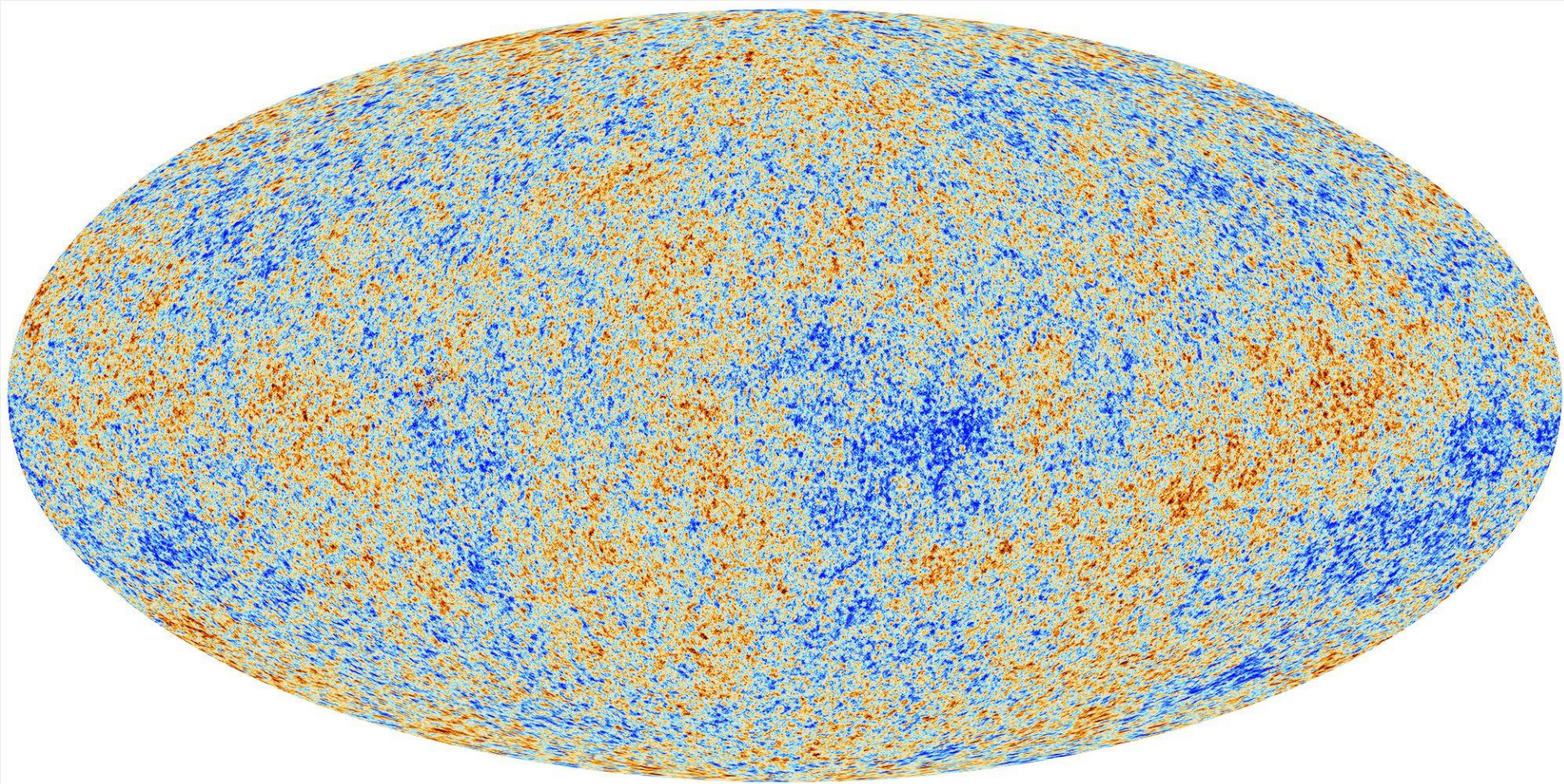




Boomerang Balloon CMB Map, 2000



Wilkinson Microwave Anisotropy Probe (WMAP), 2001-2010  
First results 2003, "Final" results ~2009.



Planck CMB mission, 2009-2013 [“Final” results ~ 2018]

