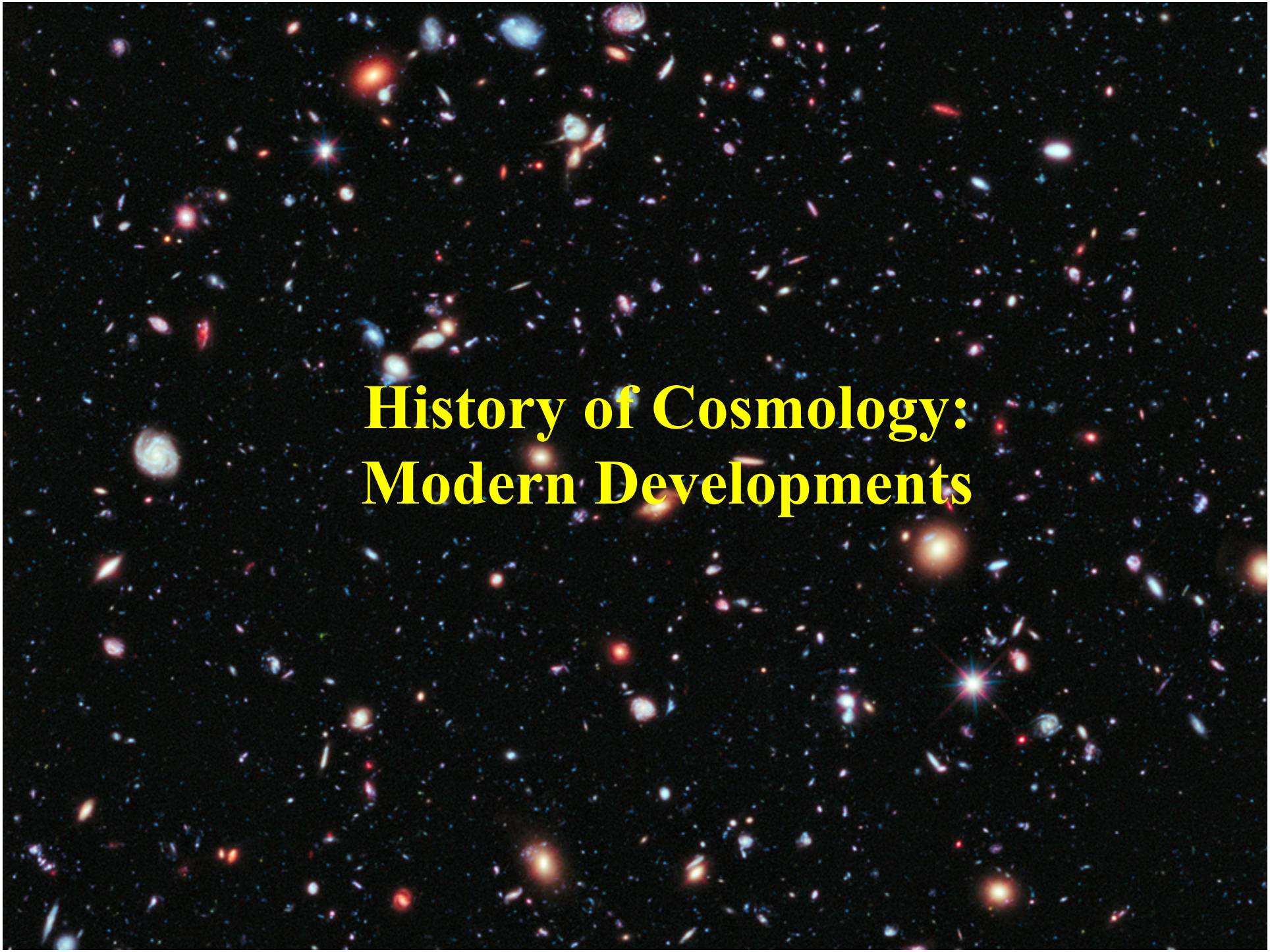
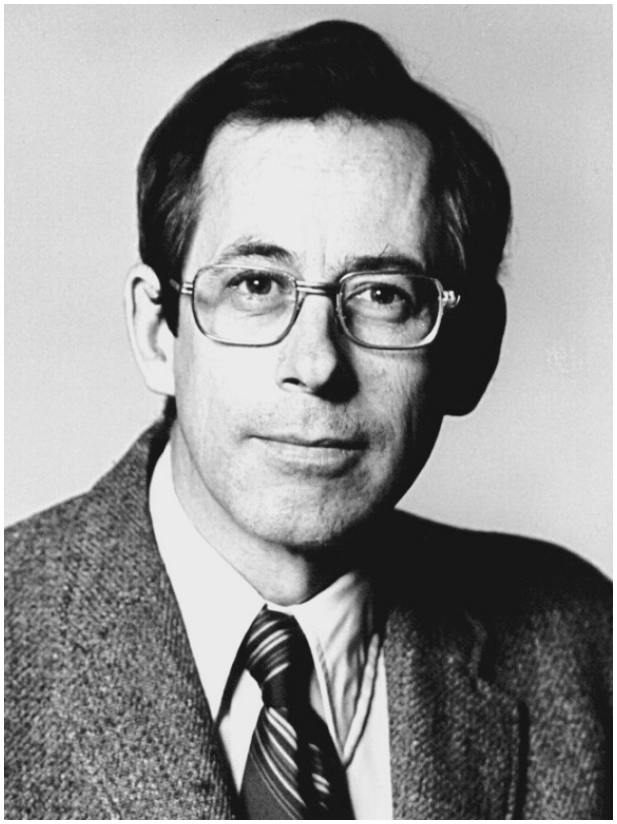
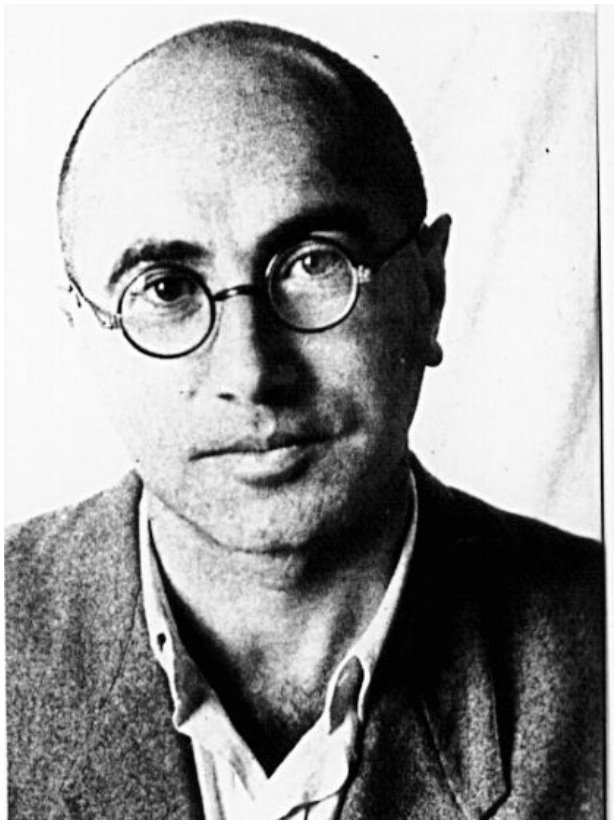

History of Cosmology:
Modern Developments

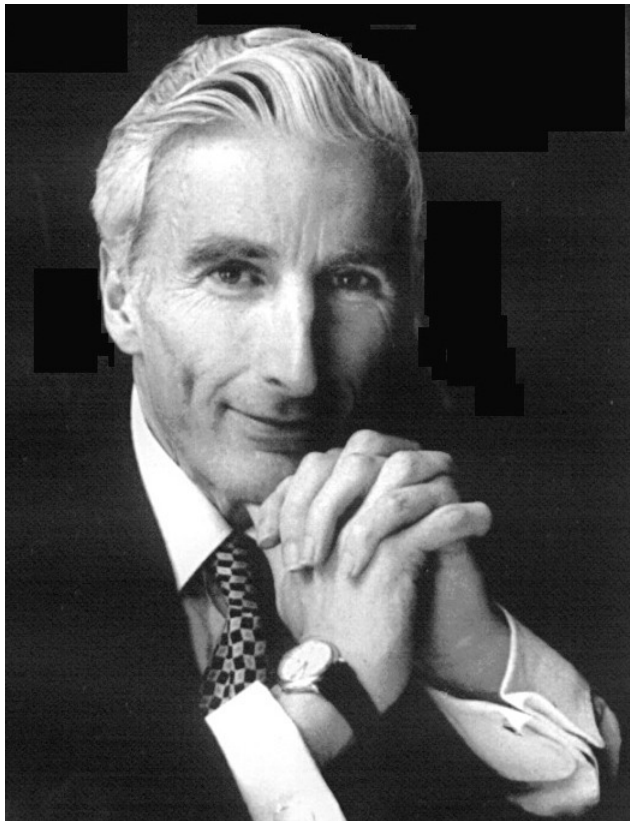
Development of Theoretical Models of Galaxy and Structure Formation: 1970's - 1990's



Jim Peebles



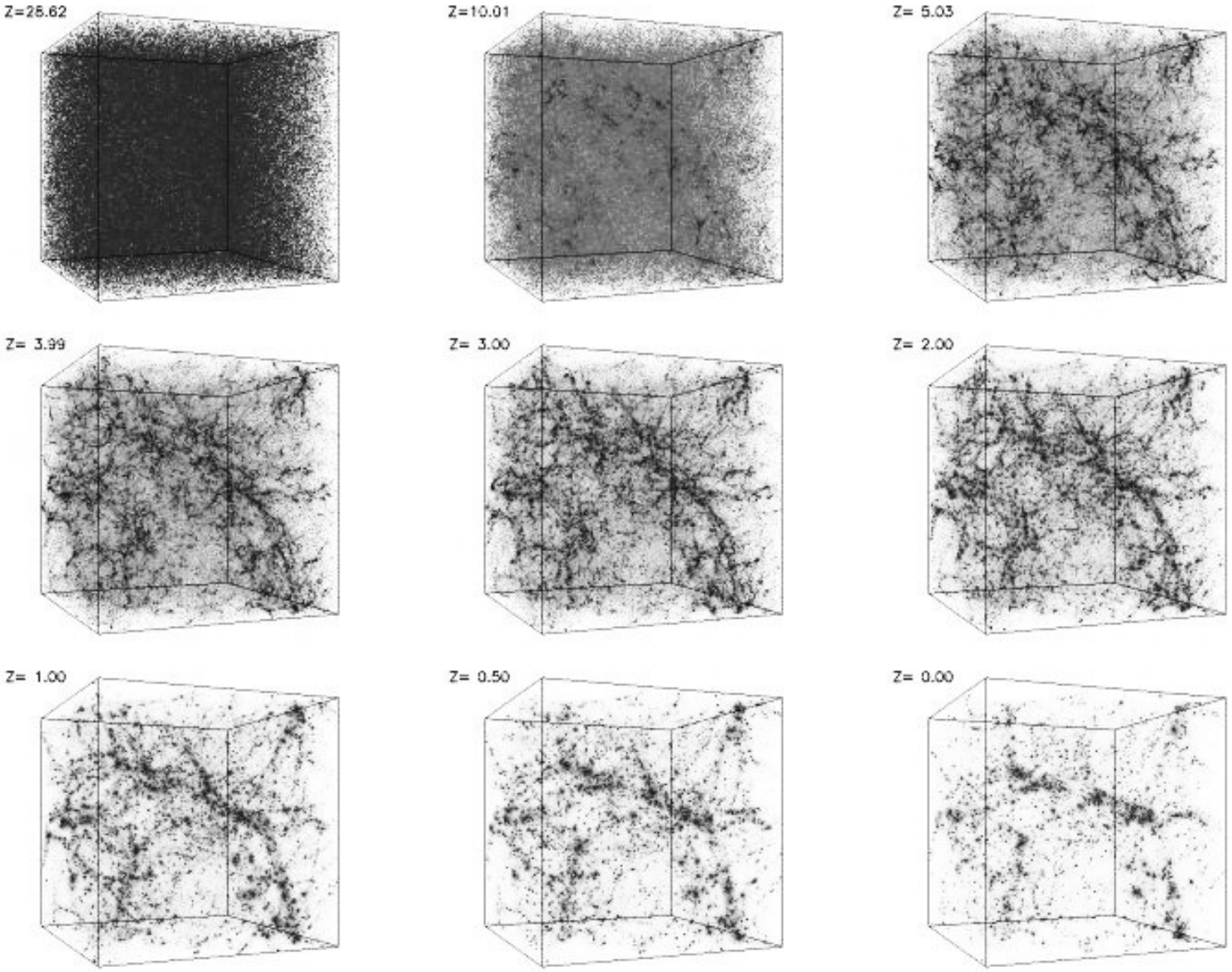
Yakov Zel'dovich



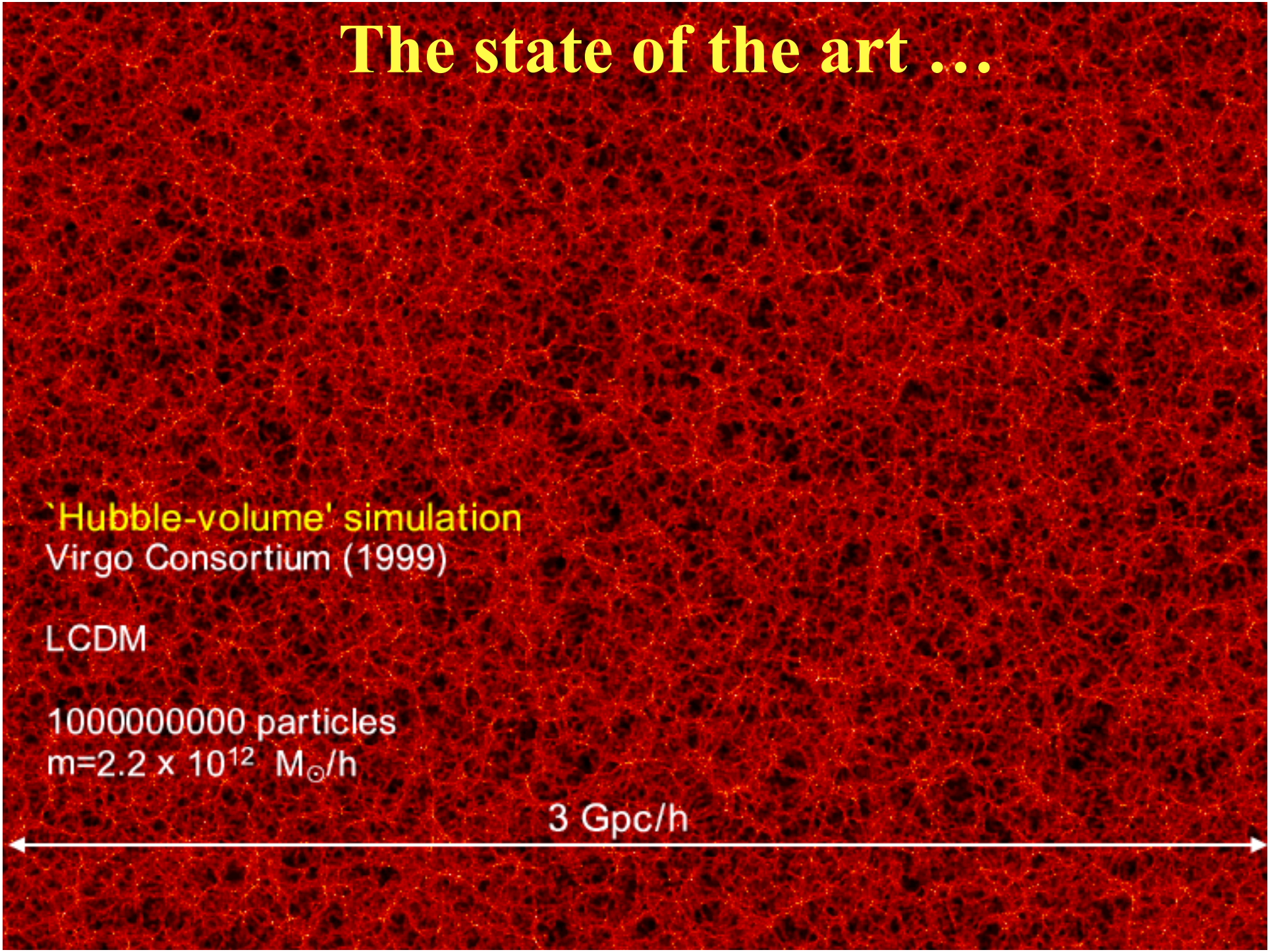
Martin Rees

Numerical Simulations of Structure and Galaxy Formation: 1970's - 2000's

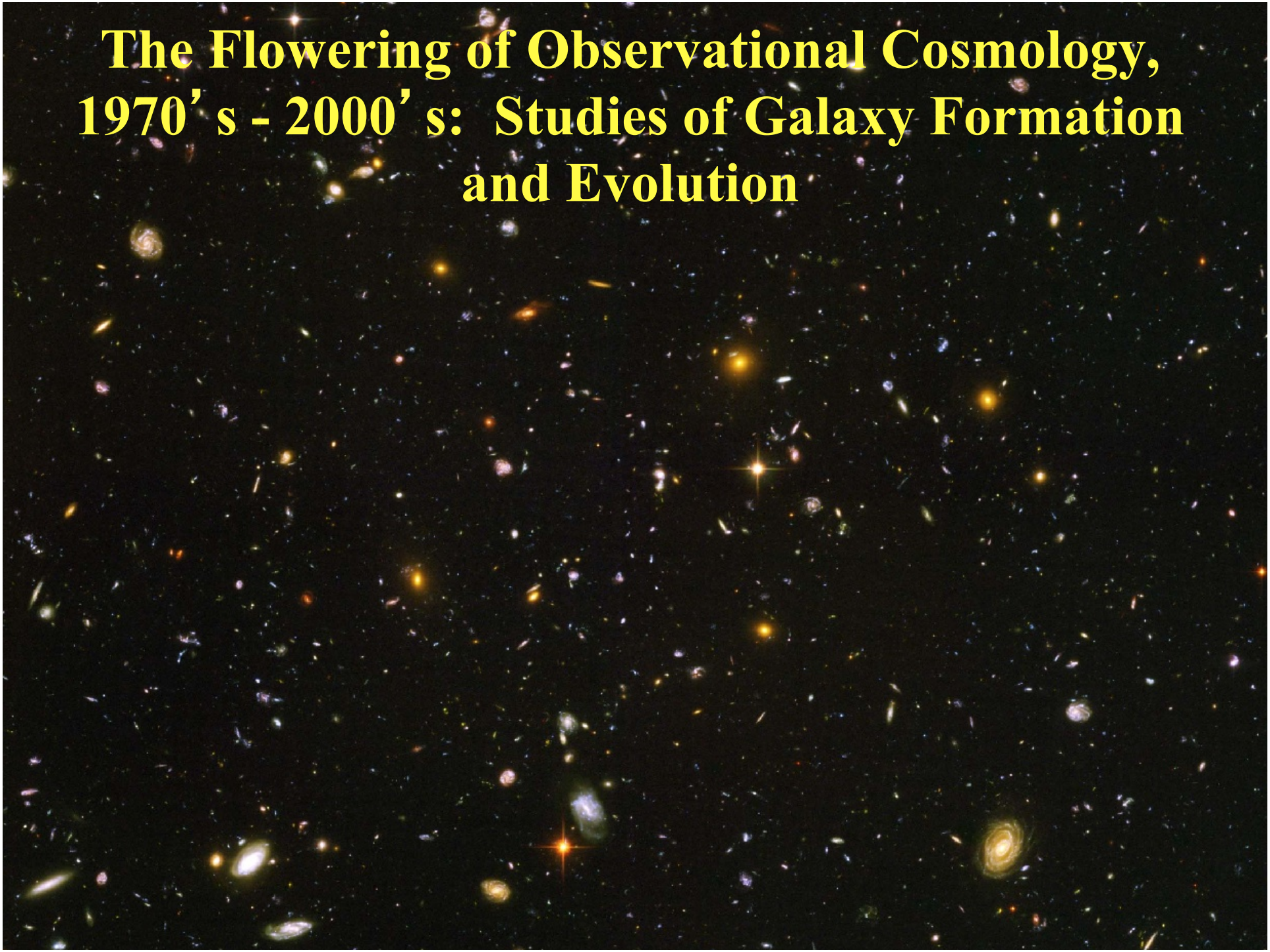
A "cosmic cube" simulation by A. Kravtsov

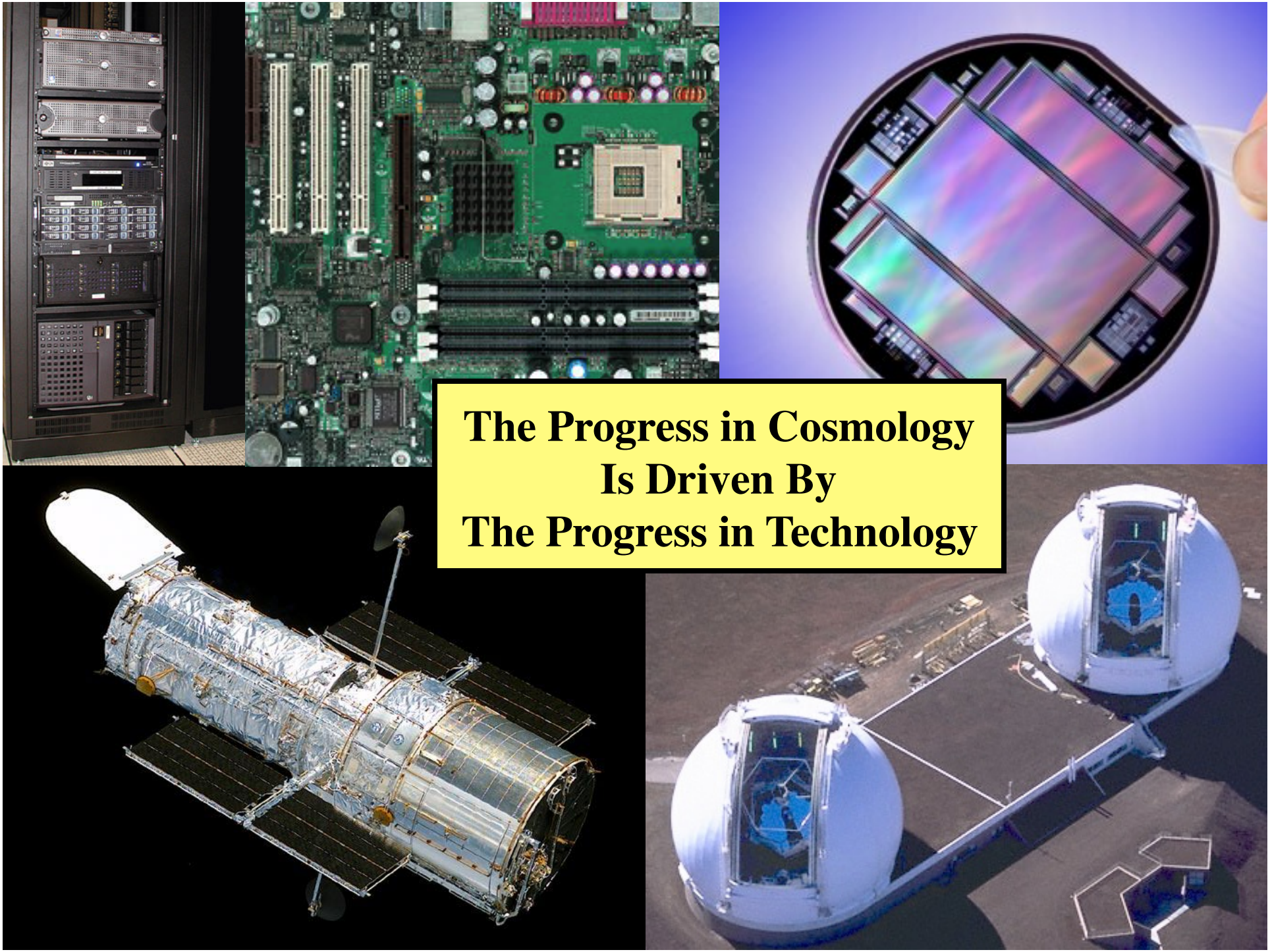


The state of the art …



The Flowering of Observational Cosmology, 1970's - 2000's: Studies of Galaxy Formation and Evolution



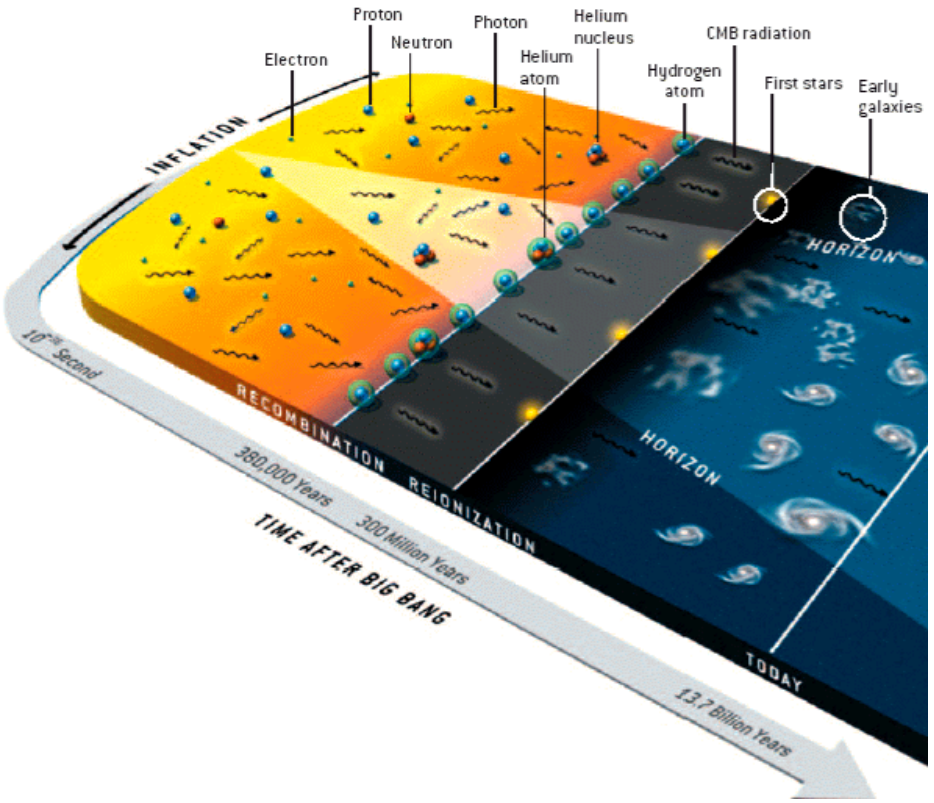

The Progress in Cosmology
Is Driven By
The Progress in Technology

Inflation: A Key Theoretical Idea

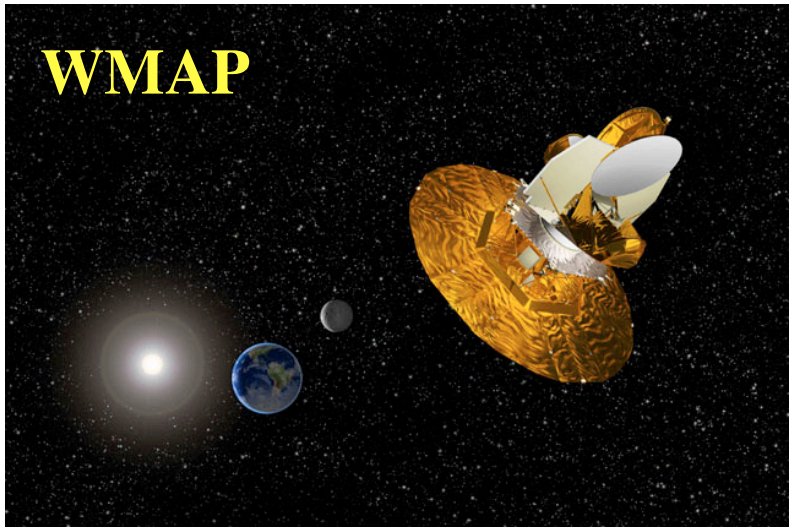
- Alan Guth (1980); precursors: D. Kazanas, A. Starobinsky
- Explains a number of fundamental cosmological problems: flatness, horizon, origin of structure, absence of topological defects…
- Chaotic inflation: Andrei Linde - is our universe just a bubble in a *much* larger megaverse?

A. Guth

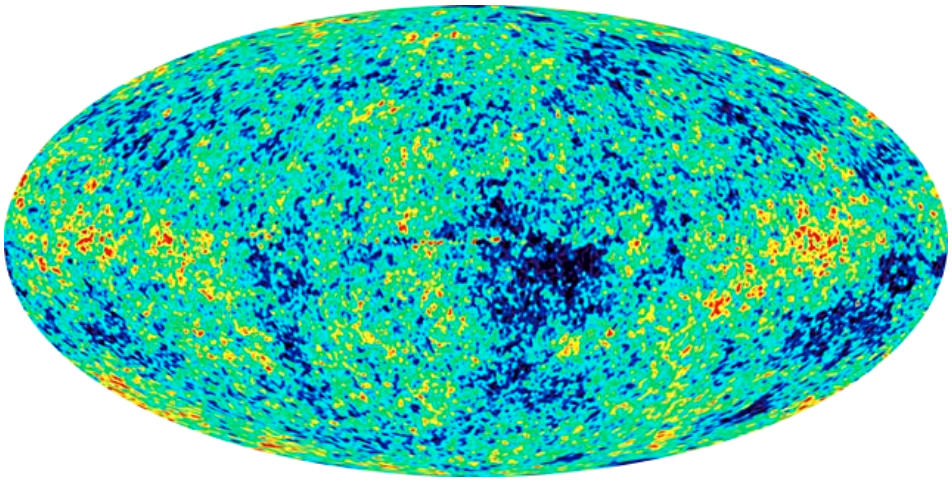
A. Linde



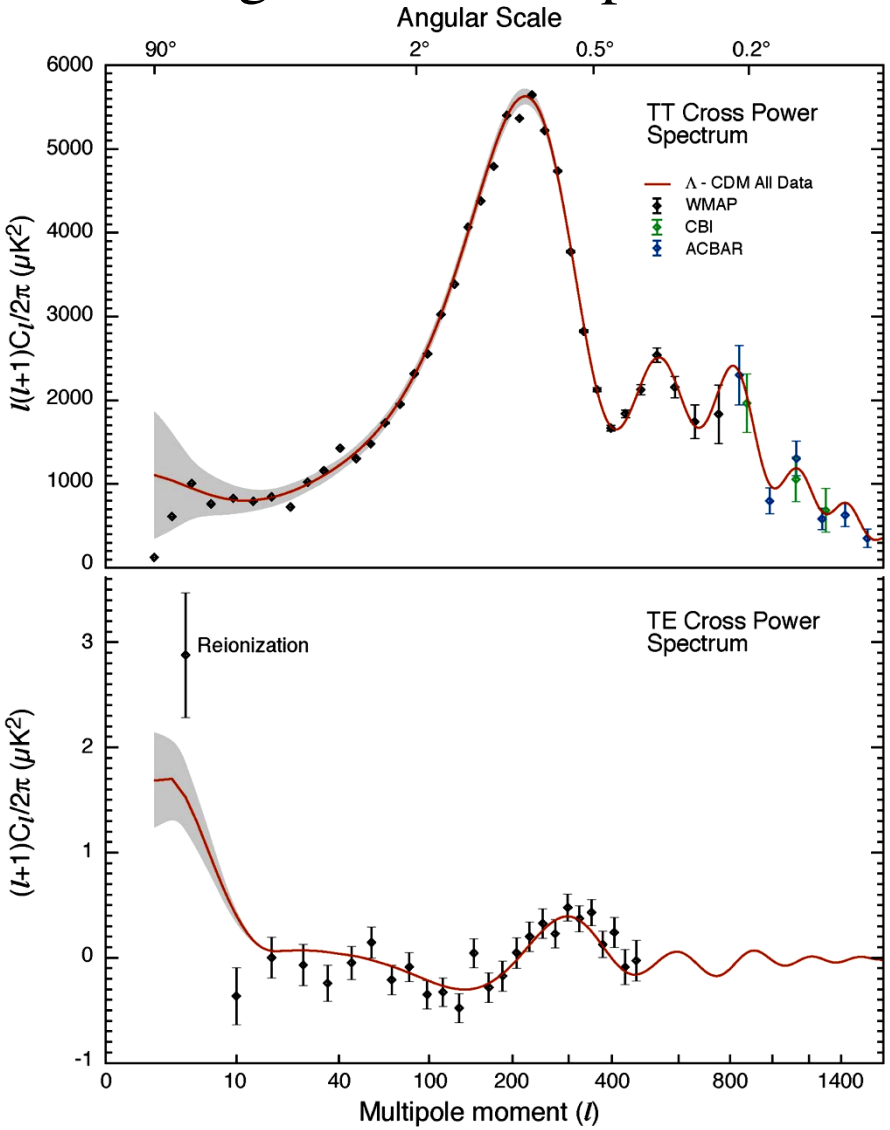
Precision Cosmology From CMBR



Temperature Fluctuations



Angular Power Spectrum



Supernova Hubble Diagram

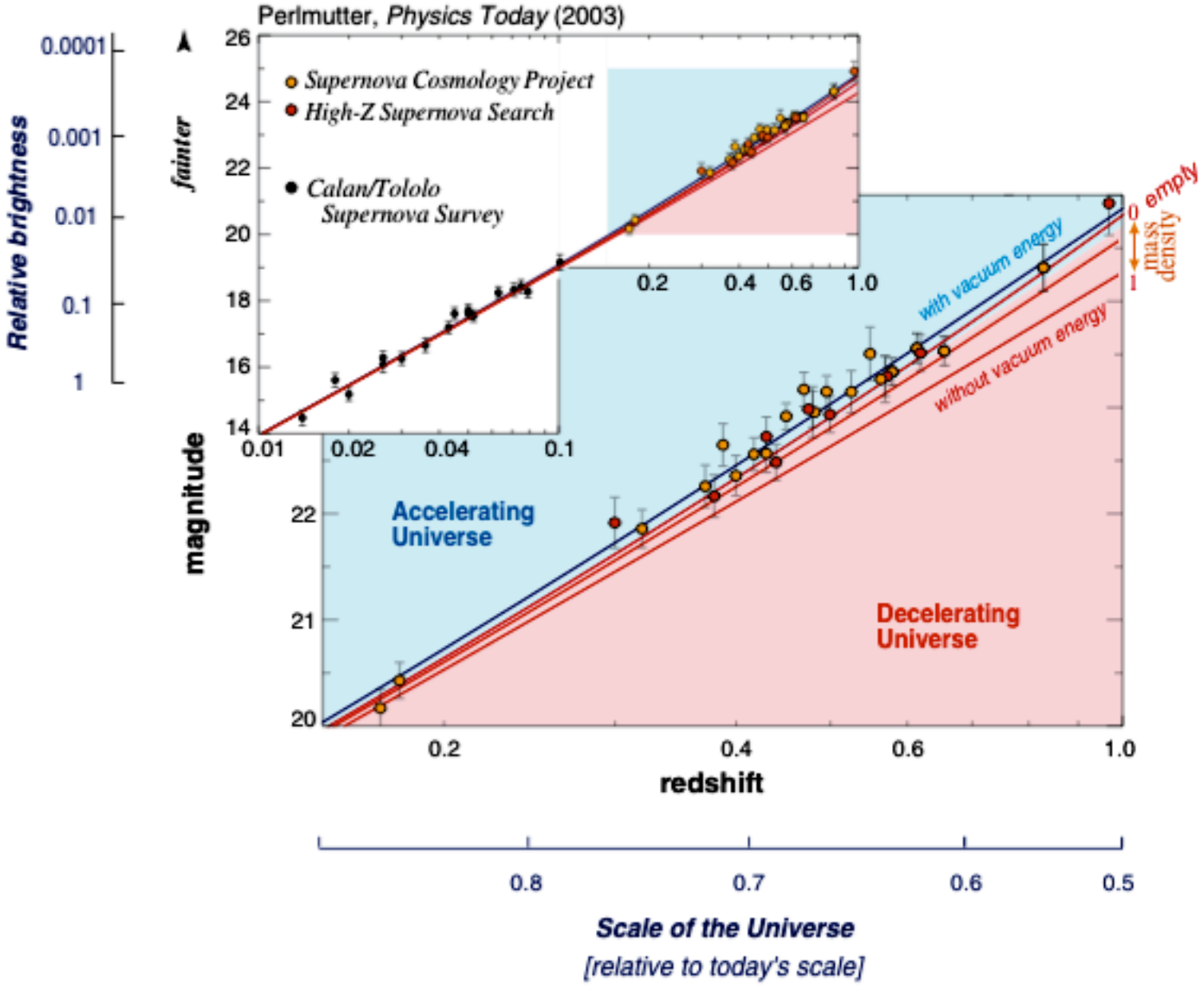


TABLE 3

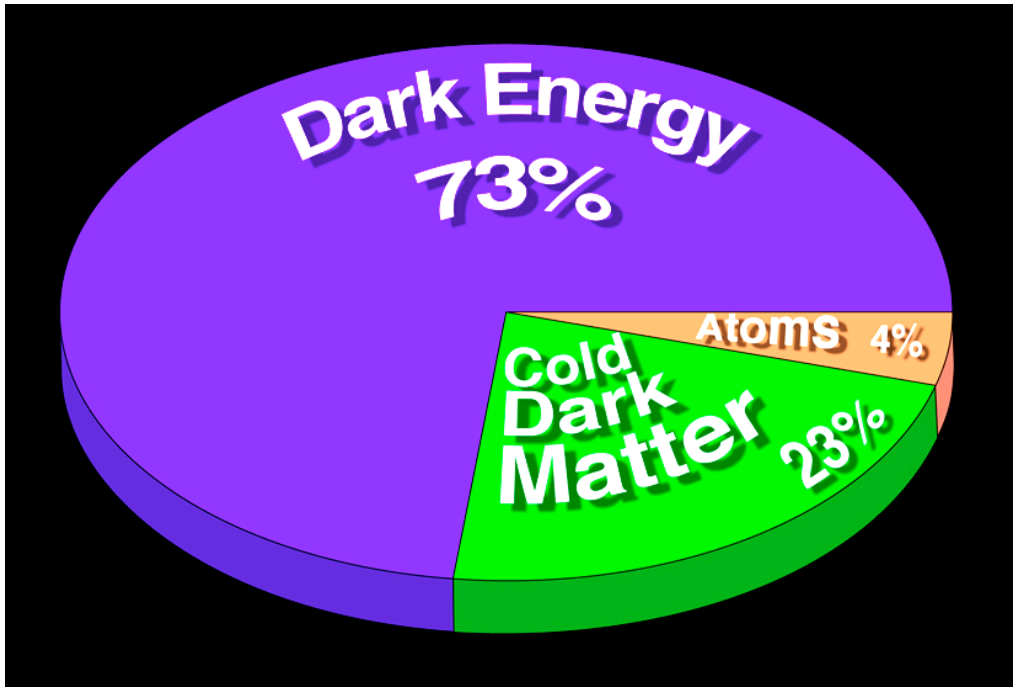
"BEST" COSMOLOGICAL PARAMETERS

Description	Symbol	Value	+ Uncertainty	− Uncertainty
Total density	$\Omega_{\rm tot}$	1.02	0.02	0.02
Equation of state of quintessence	w	<-0.78	95% CL	...
Dark energy density	Ω_Λ	0.73	0.04	0.04
Baryon density	$\Omega_b h^2$	0.0224	0.0009	0.0009
Baryon density	Ω_b	0.044	0.004	0.004
Baryon density ($\rm cm^{-3}$)	n_b	2.5×10^{-7}	0.1×10^{-7}	0.1×10^{-7}
Matter density	$\Omega_m h^2$	0.135	0.008	0.009
Matter density	Ω_m	0.27	0.04	0.04
Light neutrino density	$\Omega_\nu h^2$	<0.0076	95% CL	...
CMB temperature (K)[a]	$T_{\rm CMB}$	2.725	0.002	0.002
CMB photon density ($\rm cm^{-3}$)[b]	n_γ	410.4	0.9	0.9
Baryon-to-photon ratio	η	6.1×10^{-10}	0.3×10^{-10}	0.2×10^{-10}
Baryon-to-matter ratio	$\Omega_b \Omega_m^{-1}$	0.17	0.01	0.01
Fluctuation amplitude in 8 h^{-1} Mpc spheres	σ_8	0.84	0.04	0.04
Low-z cluster abundance scaling	$\sigma_8 \Omega_m^{0.5}$	0.44	0.04	0.05
Power spectrum normalization (at $k_0 = 0.05$ $\rm Mpc^{-1}$)[c]	A	0.833	0.086	0.083
Scalar spectral index (at $k_0 = 0.05$ $\rm Mpc^{-1}$)[c]	n_s	0.93	0.03	0.03
Running index slope (at $k_0 = 0.05$ $\rm Mpc^{-1}$)[c]	$dn_s/d\ln k$	-0.031	0.016	0.018
Tensor-to-scalar ratio (at $k_0 = 0.002$ $\rm Mpc^{-1}$)	r	<0.90	95% CL	...
Redshift of decoupling	$z_{\rm dec}$	1089	1	1
Thickness of decoupling (FWHM)	$\Delta z_{\rm dec}$	195	2	2
Hubble constant	h	0.71	0.04	0.03
Age of universe (Gyr)	t_0	13.7	0.2	0.2
Age at decoupling (kyr)	$t_{\rm dec}$	379	8	7
Age at reionization (Myr, 95% CL)	t_r	180	220	80
Decoupling time interval (kyr)	$\Delta t_{\rm dec}$	118	3	2
Redshift of matter-energy equality	$z_{\rm eq}$	3233	194	210
Reionization optical depth	τ	0.17	0.04	0.04
Redshift of reionization (95% CL)	z_r	20	10	9
Sound horizon at decoupling (deg)	θ_A	0.598	0.002	0.002
Angular size distance (Gpc)	d_A	14.0	0.2	0.3
Acoustic scale[d]	ℓ_A	301	1	1
Sound horizon at decoupling (Mpc)[d]	r_s	147	2	2

[a] From *COBE* (Mather et al. 1999).
[b] Derived from *COBE* (Mather et al. 1999).
[c] With $\ell_{\rm eff} \approx 700$.
[d] With $\ell_A \equiv \pi\theta_A^{-1}$, $\theta_A \equiv r_s d_a^{-1}$.

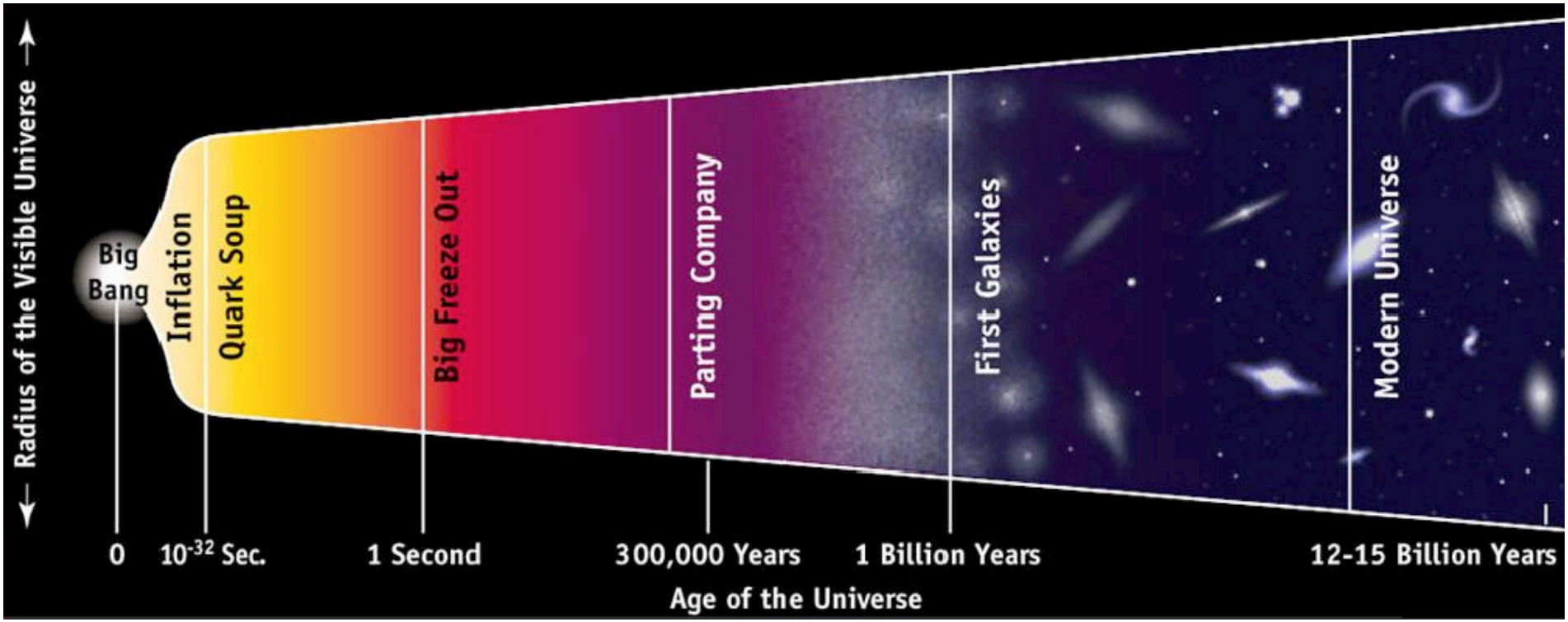
WMAP + 2dF results,
Bennett et al. 2003

The Composition of the Universe



- A picture consistent with many different observations, not just SNe and CMBR: Concordance Cosmology
- The nature of the Dark Matter and Dark Energy are among the most outstanding problems of science today

The Cosmic Timeline



Fairly well understood

The current frontier

Physics reasonably well understood

Highly speculative physics

From a Particle Physics Viewpoint:

Inflation 10^{16} GeV

Quarks → Protons
1 GeV

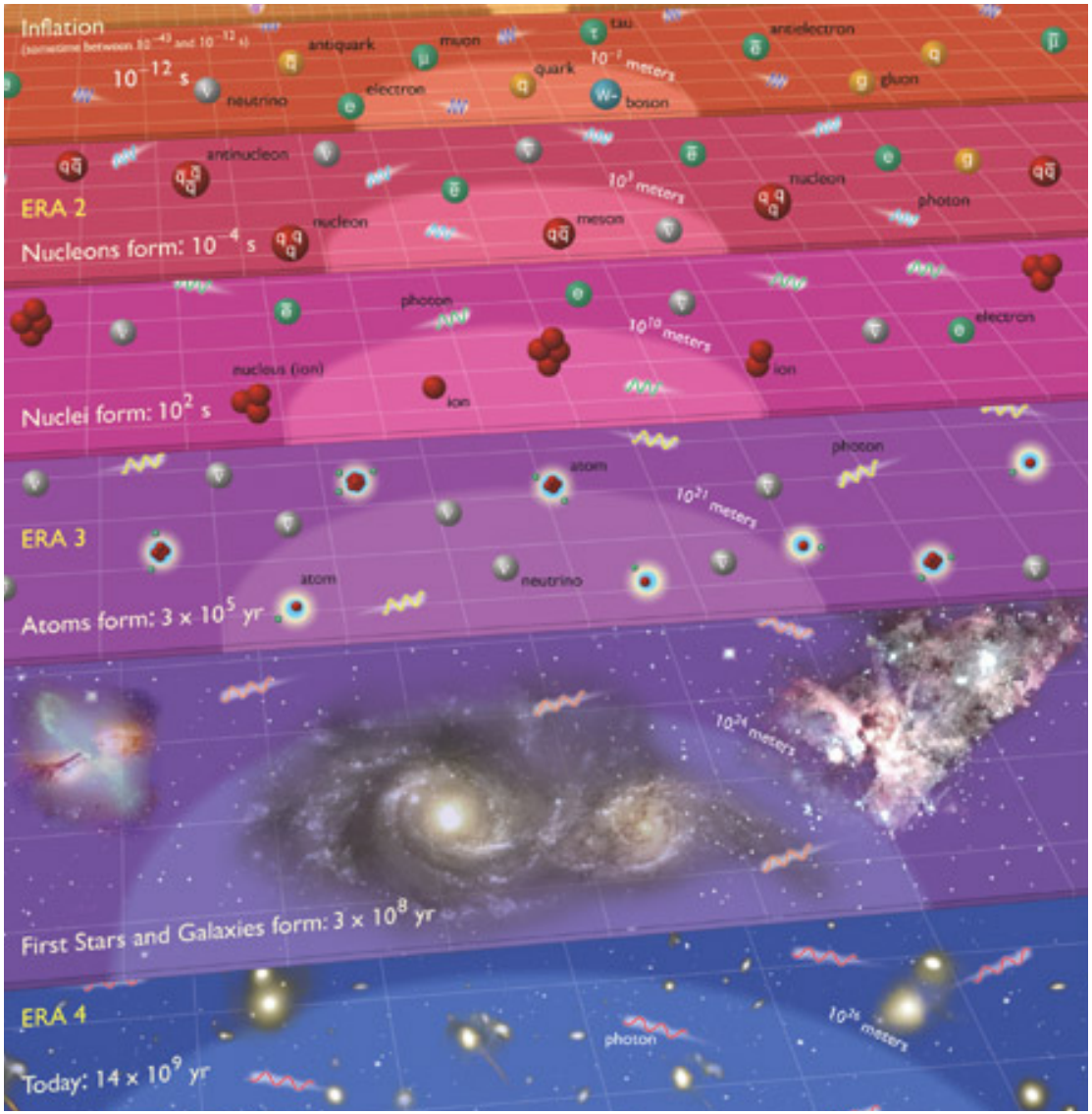
Nuclei form 1 MeV

Atoms form 1 eV

[Room temperature 1/40 eV]

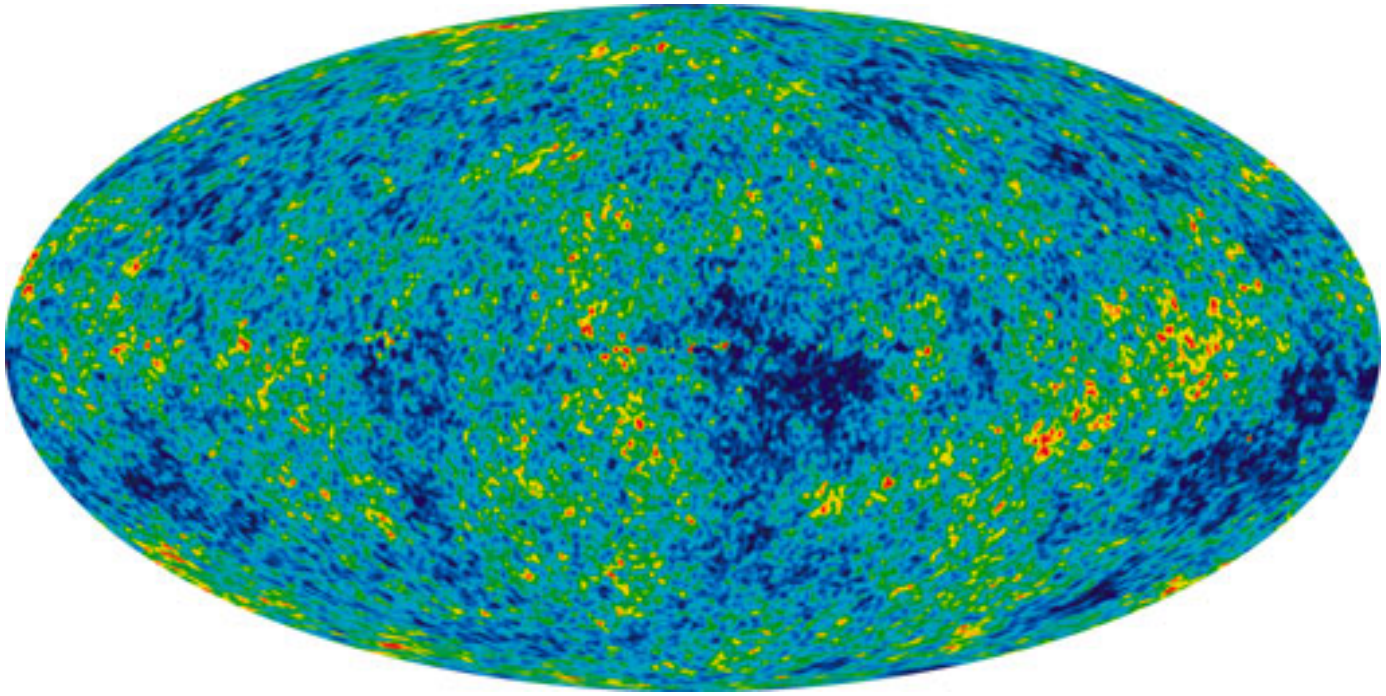
Stars and galaxies
first form: 1/40 eV

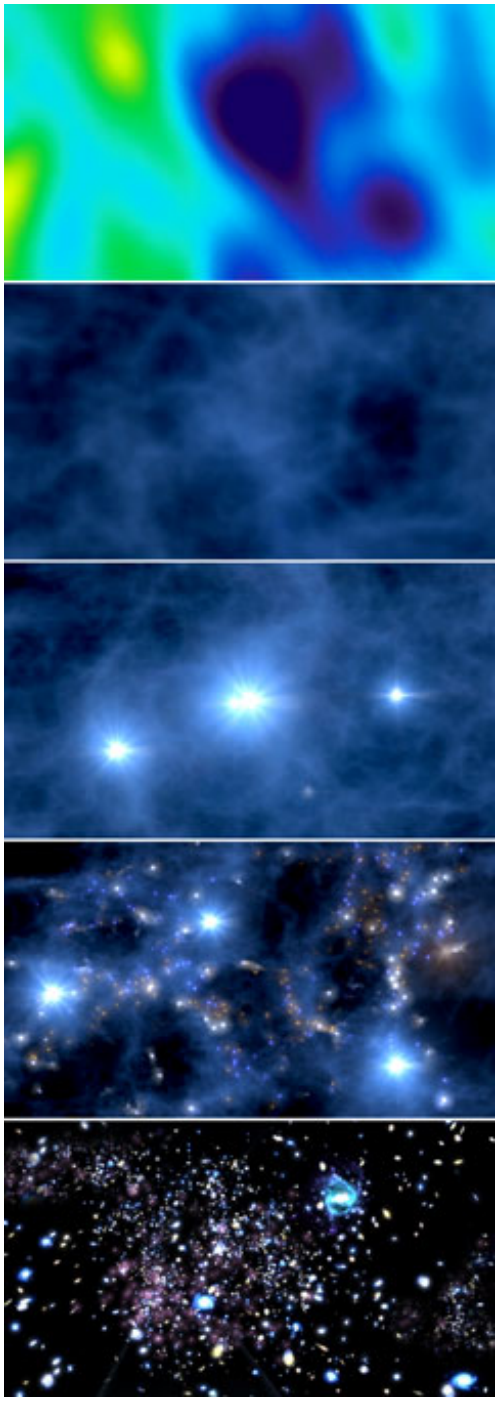
Today: 1/4000 eV



WMAP Team's Simulation of the Early Cosmic History

(Movie)





The Universe in a Day

Event	When it happened
Big Bang	12:00:00 midnight
First Atoms form	12:00:08 a.m.
Stars and Galaxies form	12:29:00 a.m.
Our Sun is born	4:00:00 p.m.
Earth born	4:38:00 p.m.
Moon formed	4:48:00 p.m.
Earliest life on Earth	5:55:00 p.m.
First multi-cellular life on Earth	10:53:00 p.m.
Dinosaurs appear	11:41:00 p.m.
Dinosaurs die	11:54:00 p.m.
Humans arise	11:59:56 p.m.
Present Day	12:00:00 midnight tomorrow
Sun becomes Red Giant	8:00:00 a.m. tomorrow
Sun becomes White Dwarf	8:19:00 a.m. tomorrow

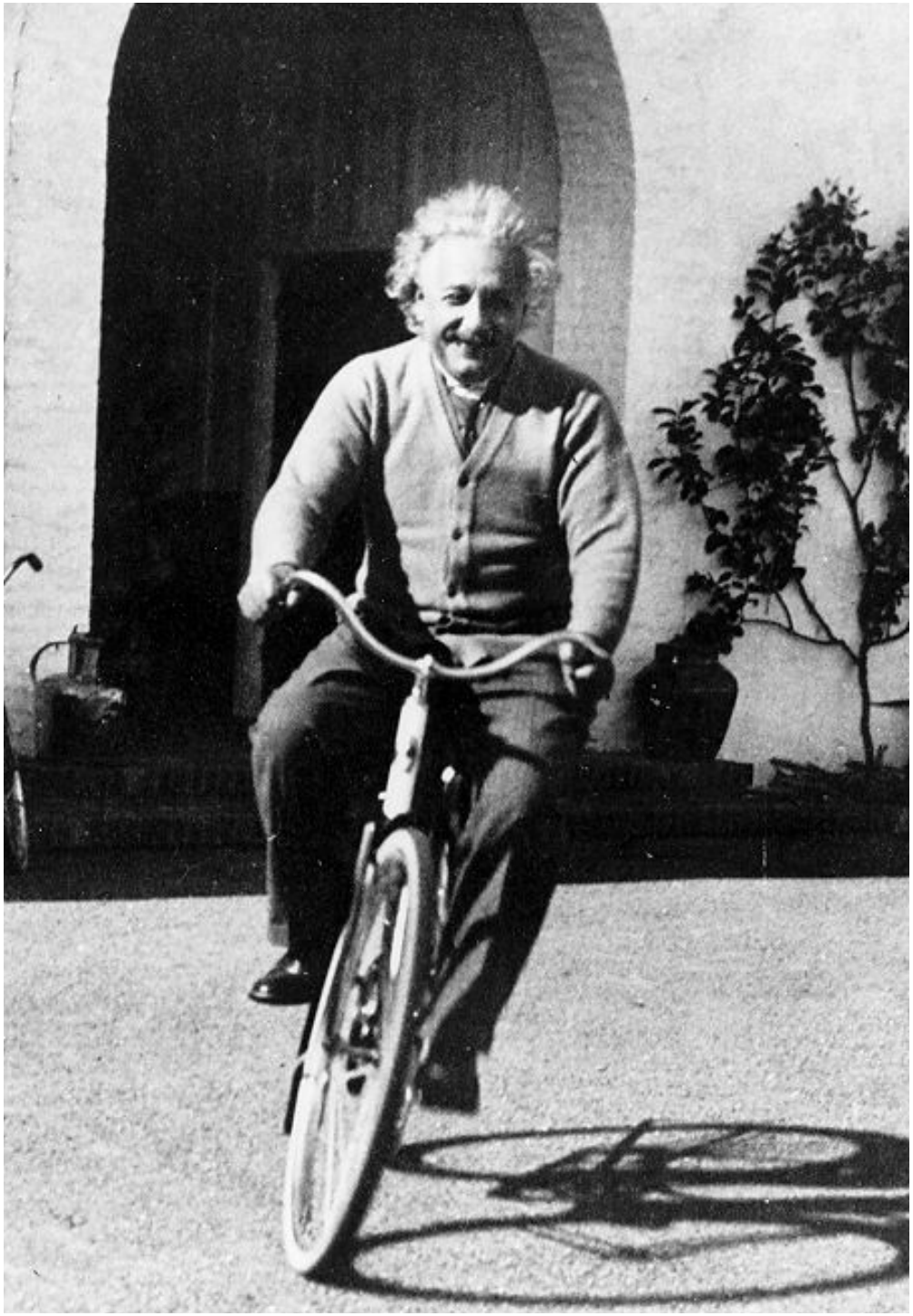
A Dichotomy of Cosmology? (M. Rees)

Theories of the early universe, inflation, nucleosynthesis, CMBR fluctuations …

Elegant, mathematical, clean

Studies of galaxy and structure formation and evolution, mostly observational, some numerics …

Lots of messy phenomenology



Next:

Relativistic Cosmology and the Global Geometry and Dynamics of the Universe