현대우주론의 가정과 한계

Modern Cosmology: Assumptions and Limits

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2006.10.10

http://bh.knu.ac.kr/~jchan/cosmology.ps

Universe (宇宙)

四方上下　曰宇

古往今來　曰宙

以喻天地

淮南子(劉安) (~150B.C.)

“The universe is real but you can’t see it.
You have to imagine it.”

Alexander Calder (1898-1976)

Cosmology (宇宙論)

"cosmology - the study of the universe at large, its history and its future."

J. Bernstein, et al (1986)

"cosmology: understanding the world including ourselves, and our knowledge, as part of the world.
All science is cosmology, I believe…. "

Karl Popper (1902-1994)

"For Popper, all science is cosmology. The only difference between scientific and philosophic cosmology is that science produces theories that are potentially falsifiable. Philosophic cosmology produces theories that are unfalsifiable, in that no experiment could never prove them false."

Situation in Cosmology (Astronomy)

- Single view
- Uncontrollable
- Unrepeatable
- Inaccessible
- Distorsion
- Unique

"Given this situation, we are unable to obtain a model of the Universe without some specifically cosmological assumptions which are completely unverifiable."

G. F. R. Ellis (1975)

Assumptions and Limits

- Good luck assumption

  "The normal physical laws we determine in our space-time vicinity are applicable at all other space-time points."

  G. F. R. Ellis (1975)

  Unverifiable!

- Scientific policy

  "Ockham's razor", minimal assumption attitude. Unverifiable!

- Uncertainty

  Both random (in measurements) and systematic (in assumptions) errors.

- Further loophole

  Any explanation may not be unique.

"The problem [is that] there is only one universe to be observed, and we effectively can only observe it from one space-time point."

G. F. R. Ellis (1975)

Metaphysical assumptions

"All science presupposes some metaphysical system of beliefs"

"As used by Aristotle the word 'metaphysics' meant 'beyond physics', that is beyond the scope of physical science."

"Metaphysical theories are absolutely essential to scientific inquiry."

"[M]odern science is based not only on observation and experiment but also on metaphysical beliefs. [F]aith or trust is necessary for understanding the natural world."

J. Trusted (1991)

"It is always good to know which ideas cannot be checked directly, but it is not necessary to remove them all. It is not true that we can pursue science completely by using only those concepts which are directly subject to experiment."

R. Feynman (1964)

Theoretical World Models

Four ingredients (assumptions):

1. Gravity: Einstein gravity or generalized gravity
2. Spatial geometry: homogeneous and isotropic, or more complicated geometries.
3. Matter contents: dust, radiation, fields, and others.
4. Topology (global geometry): undetermined in the gravity level.

Smoothed spatial geometry

CMB are quite isotropic (same in all directions) around us.

Do we have any evidence that the same isotropy holds in other places?

unverifiable, globally in principle, locally in practice!

We need a dogma: the part we see is representative of the whole

"Whatever spot anyone may occupy, the universe stretches away from him just the same in all directions without limit."

Lucretius (A Roman citizen, ~ 100-55B.C.)

"If we are concerned with the structure only on a large scale, we may represent matter to ourselves as being uniformly distributed over enormous spaces, …"

A. Einstein (1917)

"dogma: a belief or set of beliefs held by a group or organization, which others are expected to accept without argument."

The Oxford Advanced Learner's Dictionary, Sixth Edition

Cosmological Dogma

Cosmological principle: "The universe is spatially homogeneous."

Global assumption. Leads to a highly idealized complete world model.

Completely unverifiable outside horizon.

Copernican principle: "We are not at the centre of the universe."

Local assumption. Leads to a model of the observed part of the universe.

No assumption outside horizon. Still difficult to prove.

G. F. R. Ellis (1975)

"Principles in cosmology have often connoted assumptions unsupported by evidence, but without which the subject can make no progress."

Martin Rees (2000)

History

Gravity:

1687 Newton
1915 Einstein

Cosmology:

1917 Einstein: static world model
1922 Friedmann: dynamic world model
1929 Hubble: expansion
1965 Penzias-Wilson: CMB
1981 Inflation (early acceleration) hypothesis
1992 COBE: CMB temperature anisotropies
1997 Recent acceleration

Observational facts

1. Our universe exists

We know for sure.

> “Not how the world is, is the mystical, but that it is.”
>
> Ludwig Wittgenstein (1922)

It is a philosophic statement.

> “Philosophy begins in wonder. And, at the end, when philosophic thought has done its best, the wonder remains.”
>
> A. N. Whitehead (1861-1947)

> “Science is what you know, philosophy is what you don't know.”
>
> Bertrand Russell (1872-1970)

2. Darkness of the night sky

"Why is the sky dark at night? The answer to this old and celebrated riddle seems deceptively simple: The Sun has set and now shines on the other side of the Earth. But, … The riddle becomes: Why are the heavens not filled with light? Why is the universe plunged into darkness? … Misleading trails of inquiry and strange discoveries abound in the quest for the solution to the riddle of cosmic darkness."

Edward Harrison (1987)

The finite age of our observable patch plus finite speed of light resolves the issue in the standard model

Johannes Kepler (1610)
Edgar Allen Poe (1848) "Eureka"

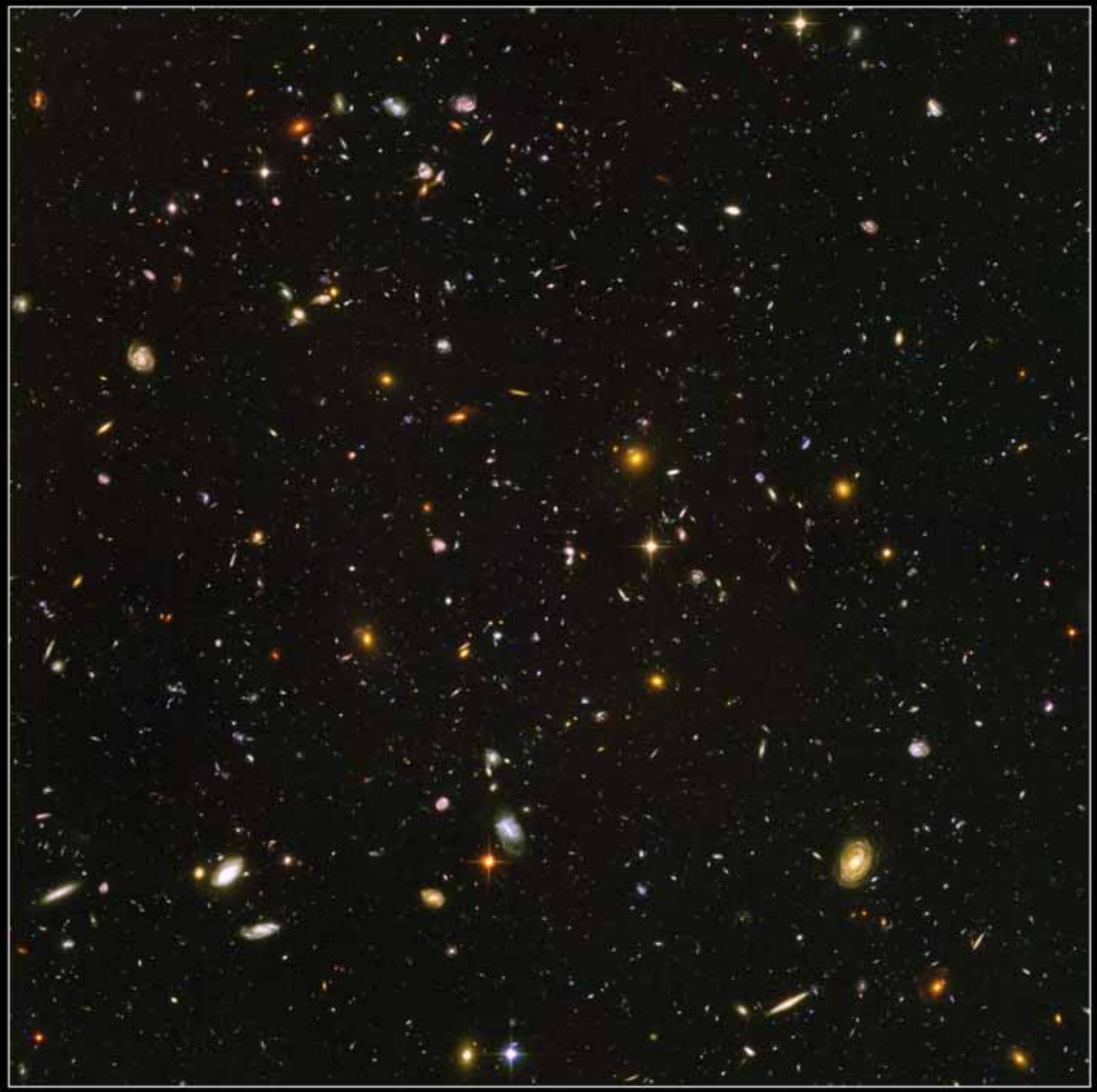
EUREKA:

A PROSE POEM

BY

EDGAR A. POE.

NEW-YORK:
GEO. P. PUTNAM,
OF LATE FIRM OF "WILEY & PUTNAM,"
155 BROADWAY.
MDCCCXLVIII.



HST

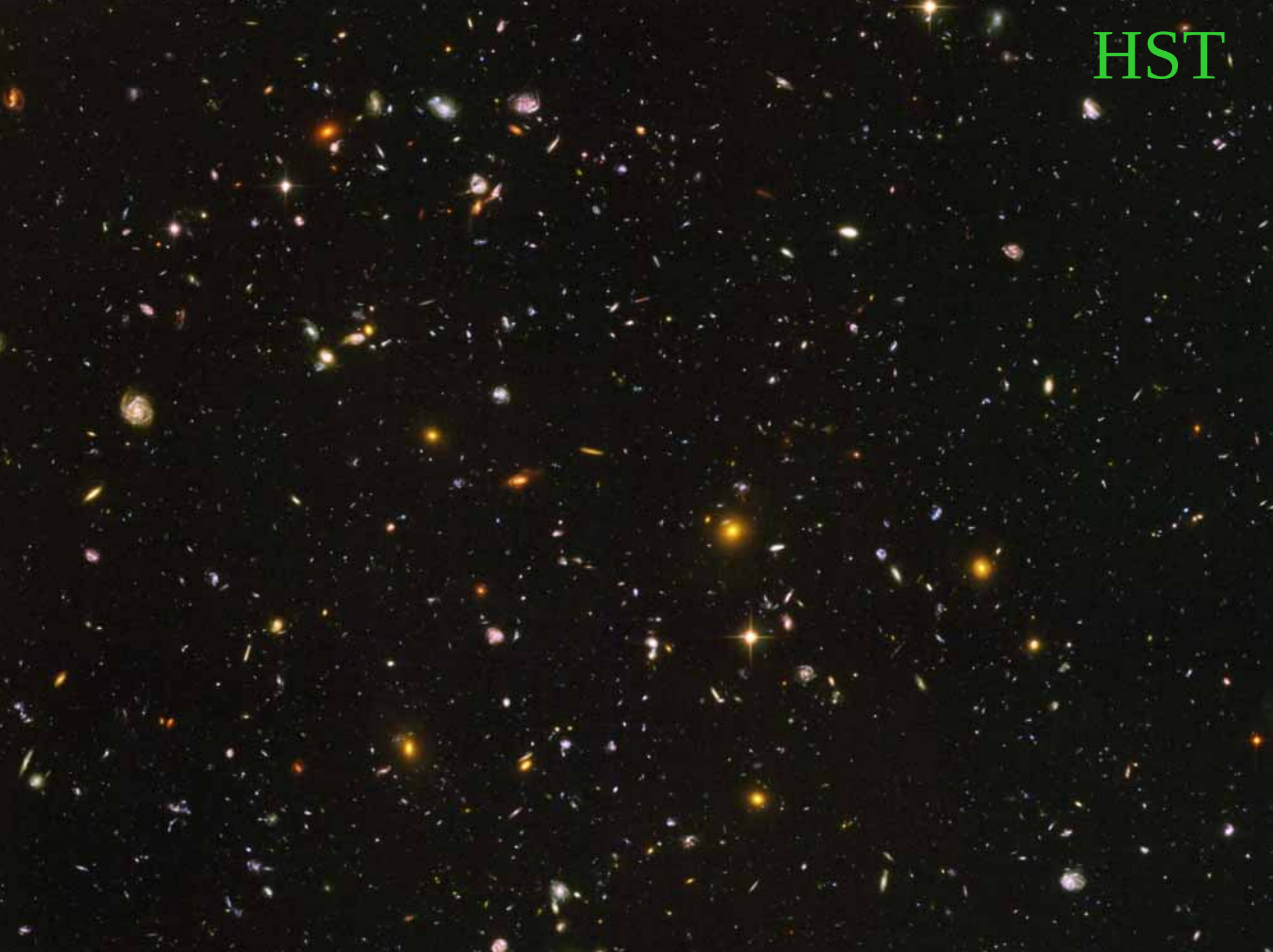
N

E

Fornax constellation , ~10,000galaxies

Hubble Ultra Deep Field

3arcmin square, net exposure 11.3days


HST

3. Large-scale distribution

- Observations find not much inconsistency with the cosmological principle on scales larger than, say, ~ several 100Mpc.
- Observed inhomogeneities can be approximated as small deviations.
- Can we say better than that?

4. Redshift-distance relation

- The redshift z is proportional to the distance d:

  $$z\,c \sim H\,d$$

- Interpreted as due to the recession of the galaxies:

  $$v \sim z\,c \quad \text{for} \quad v \ll c.$$

  Difficult to prove!

- Currently favored value shows

  $H_0 = 72 \pm 7$ km/sec/Mpc (HST)

  $H_0 = 71 \pm {}^{4}_{3}$ km/sec/Mpc (WMAP)

- and acceleration.

Henrietta Leavitt

FIGURE 18.7
Henrietta Leavitt Henrietta Swan Leavitt (1868–1921) worked at the Harvard College Observatory as one of a number of underpaid women "computers." Studying photographs of the Magellanic Clouds, she found over 1700 variable stars, including 20 cepheids. Since all the cepheids in these systems were at roughly the same distance, she was able to compare their luminosities and periods of variation, and discovered a relationship between these characteristics that led to a new and much better way of estimating cosmic distances. (Harvard College Observatory Archives)

Vesto Slipher

FIGURE 25.16
Vesto M. Slipher, 1875–1969 (Lowell Observatory)

Edwin Hubble
Milton Humason

Edwin Hubble (1889–1953)
(Photo by J. Stokley/A.S.P. Archives)

Milton Humason

Milton Lasalle Humason was born in Dodge Center, Minnesota, on 19 August 1891. As a young man he worked for a time as a mule driver on Mount Wilson, and then in 1917 he became a night assistant for the telescopes there. A student taught him the art of astronomical photography, and Humason showed such talent for the work that in 1922 he was appointed assistant astronomer. Before long he was unrivaled in the photography of the spectra of faint nebulae, and the former mule driver proved an invaluable assistant and partner to Edwin Hubble. Humason retired in 1957, and died on 18 June 1972.

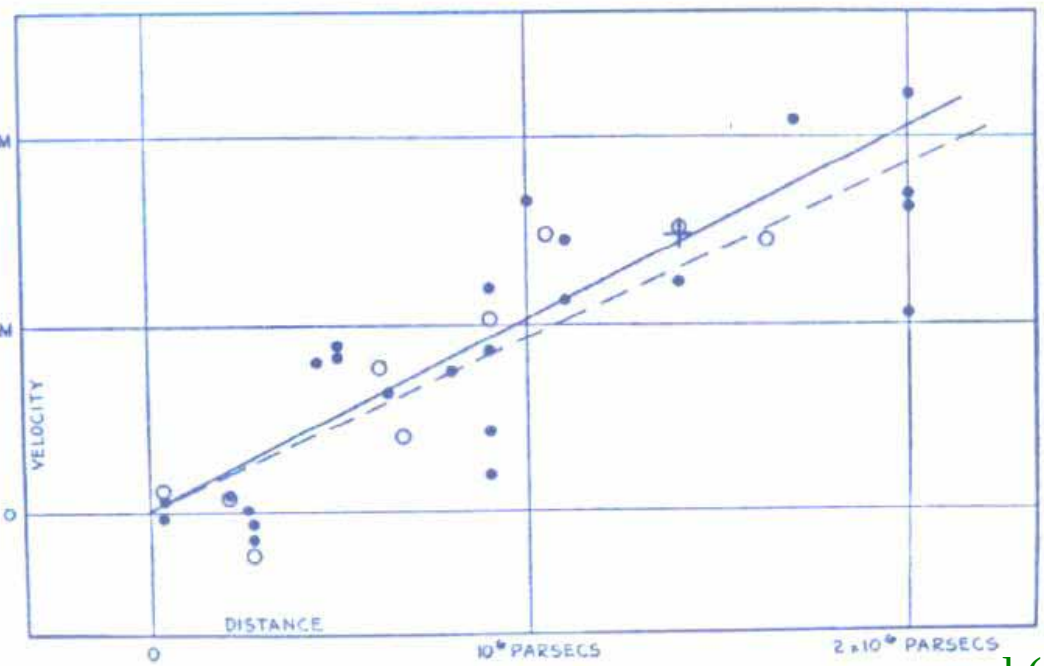
Hubble diagram

z (redshift)

$v = 1000\ \mathrm{km/sec} \leftarrow$ +1000 KM

$z \approx \frac{v}{c} \approx 0.0033$

$d = \frac{v}{H} \approx \frac{10}{h}\ \mathrm{Mpc}$



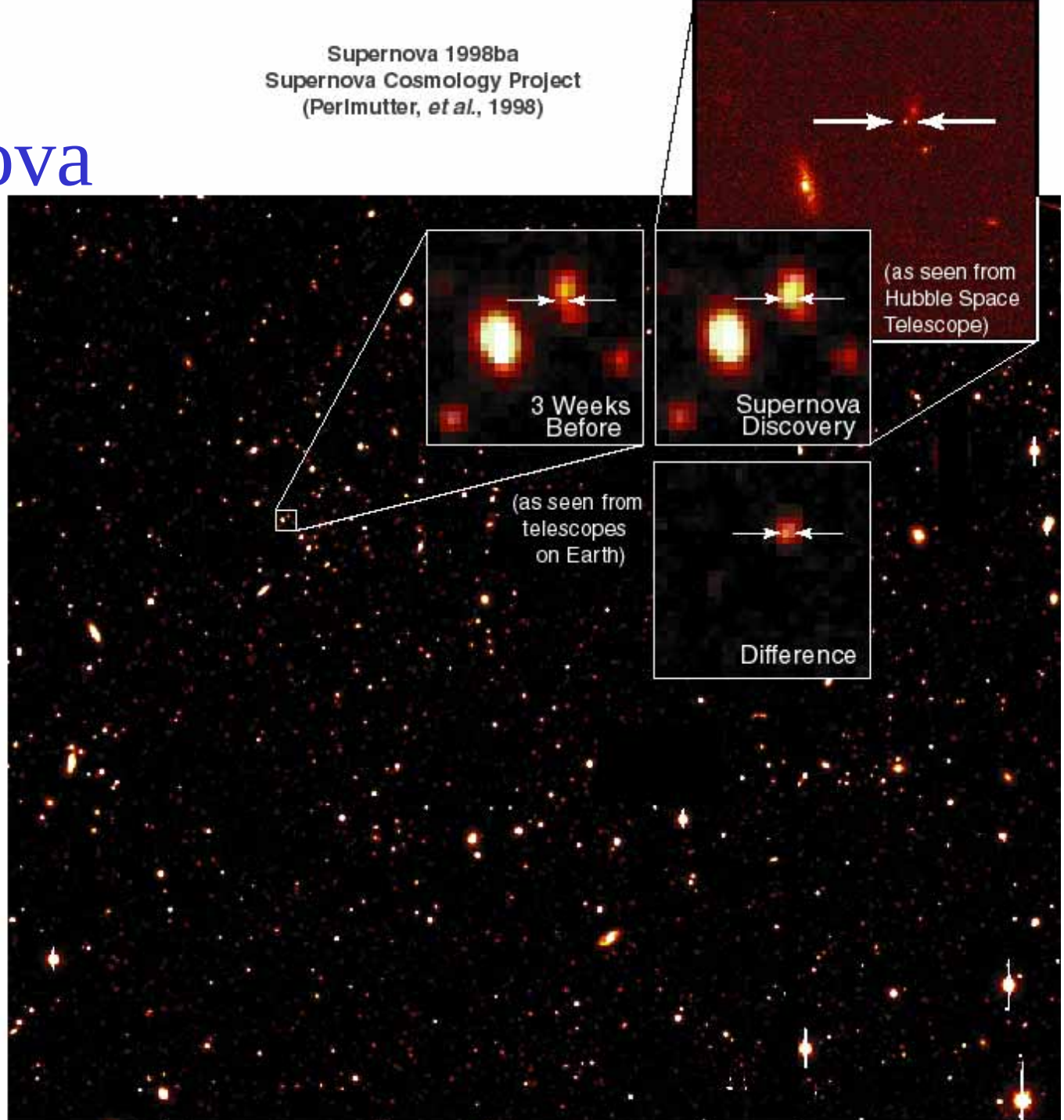
d (distance)

FIG. 9. *The Formulation of the Velocity-Distance Relation.*

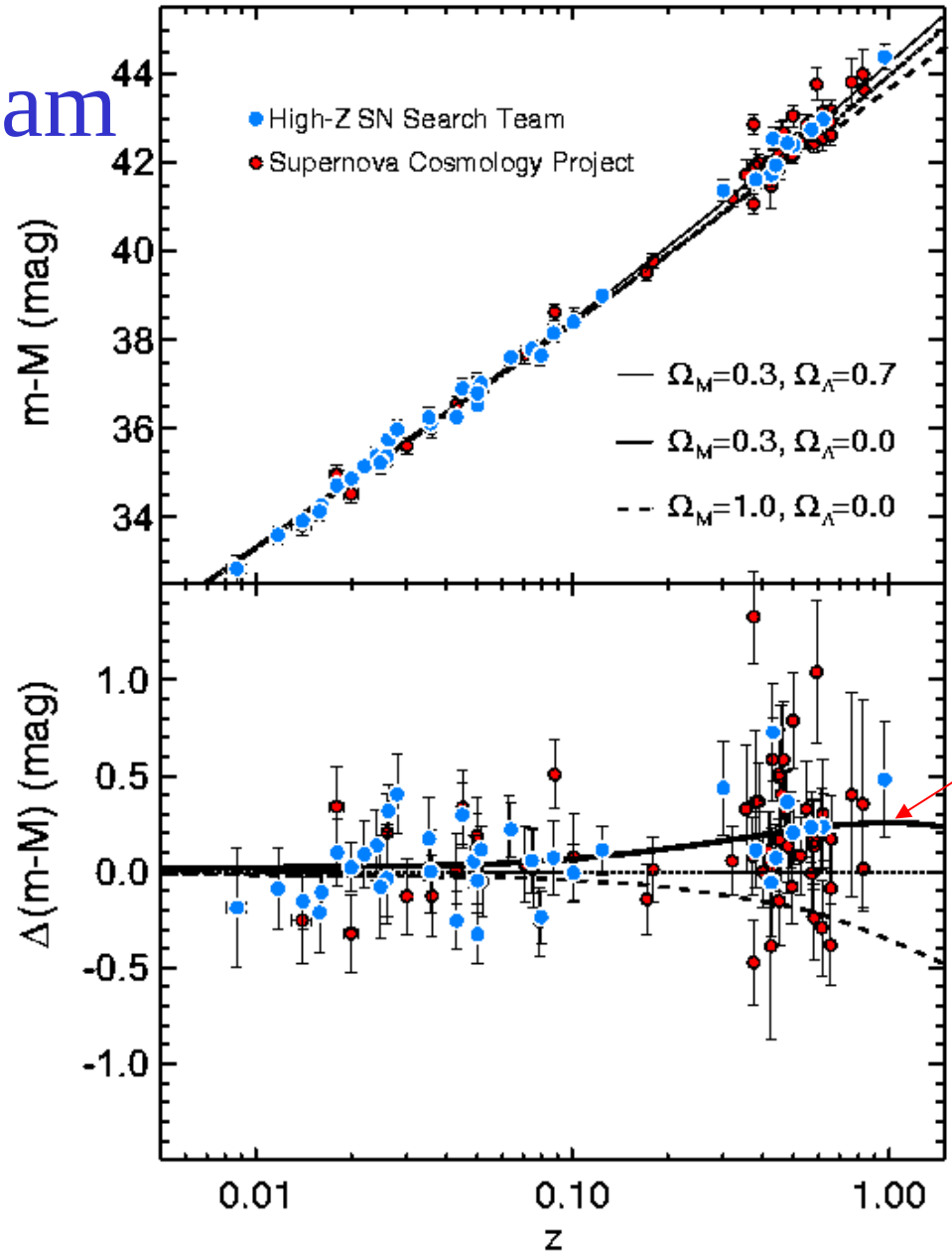
The radial velocities (in km/sec.), corrected for solar motion, are plotted against distances (in parsecs) estimated from involved stars and, in the case of the Virgo cluster (represented by the four most distant nebulæ), from the mean luminosity of all nebulæ in the cluster. The black disks and full line represent a solution for the solar motion using the nebulæ individually; the circles and dashed line, a solution combining the nebulæ into groups.

Hubble (1929)

High-z Supernova



Type Ia SN Hubble diagram

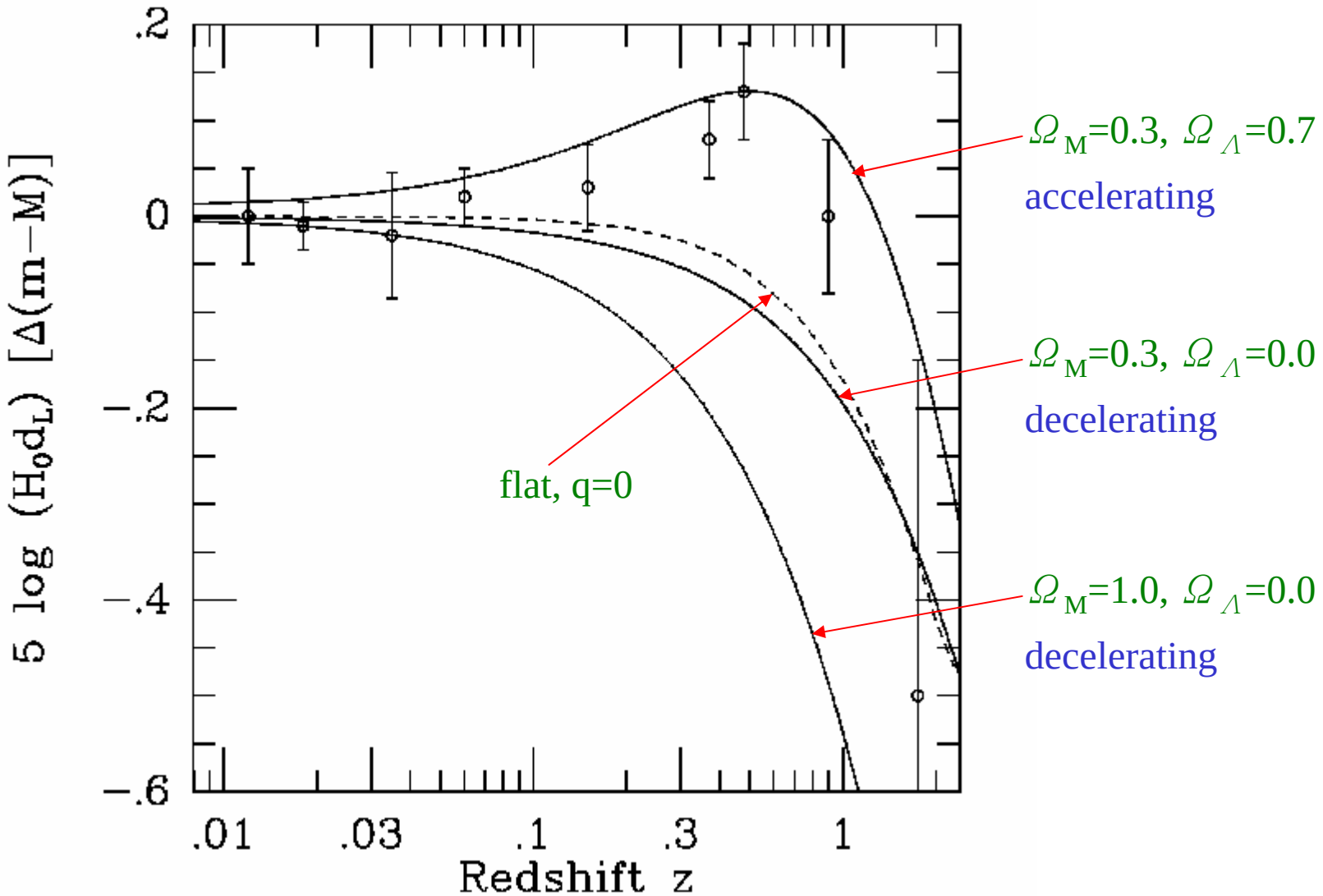


Accelerating
70% DE
repulsive!

http://cfa-www.harvard.edu/cfa/oir/Research/supernova/home.html

Type Ia SN

Residual Hubble diagram



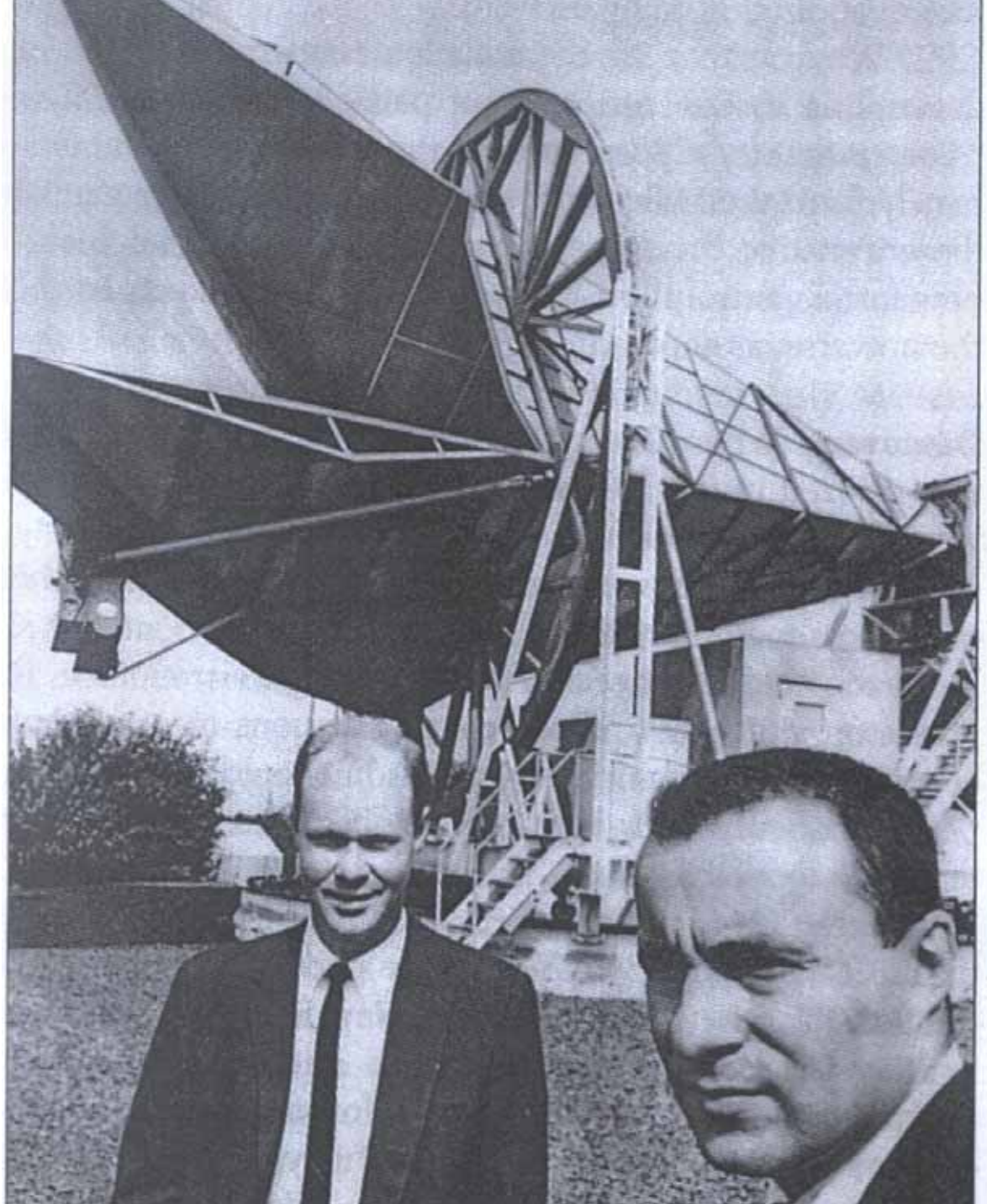
9 binned data of 200Type Ia SNs

Freeman and Turner (2003)

5. CMB

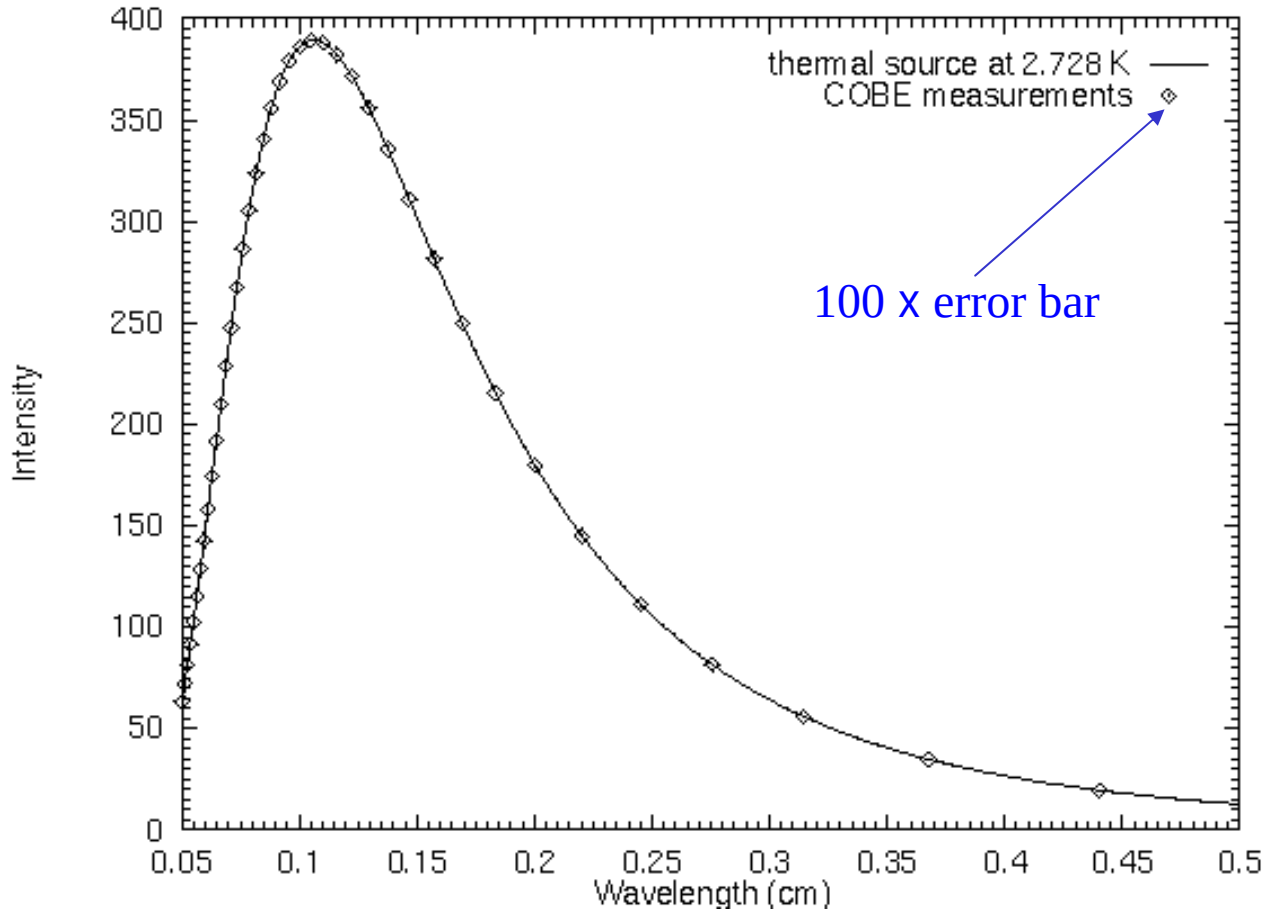
- Black-body with T~2.725K: implies ‘hot’ early universe.
- Dipole anisotropy at 10^{-3} level:
  perhaps due to our own relative motion relative to the CMB rest frame
- Multipole anisotropies at 10^{-5} level:
  due to physical processes and the gravitational clustering properties at recombination.
- Anisotropy spectrum: consistent with the Harrison-Zel'dovich’s suggestions in the 70’s.
- According to the ‘standard scenario’ we are looking at the last scattering (recombination) surface which occurred at z ~1,000 and t ~380,000yrs.
- Is CMB cosmological? Difficult to prove!

Robert Wilson
Arno Penzias



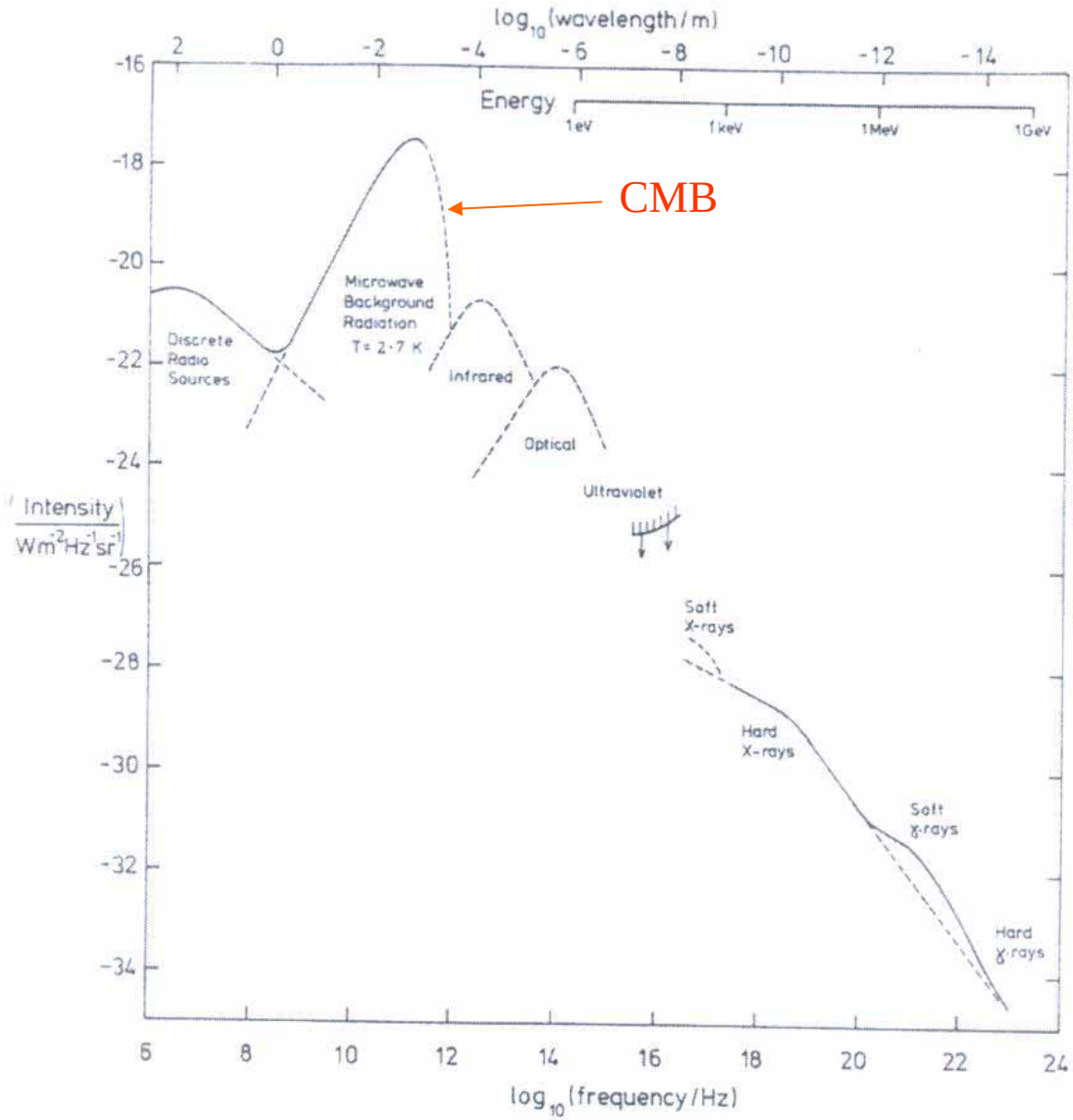
CMB Spectrum

Mather, et al (1990)



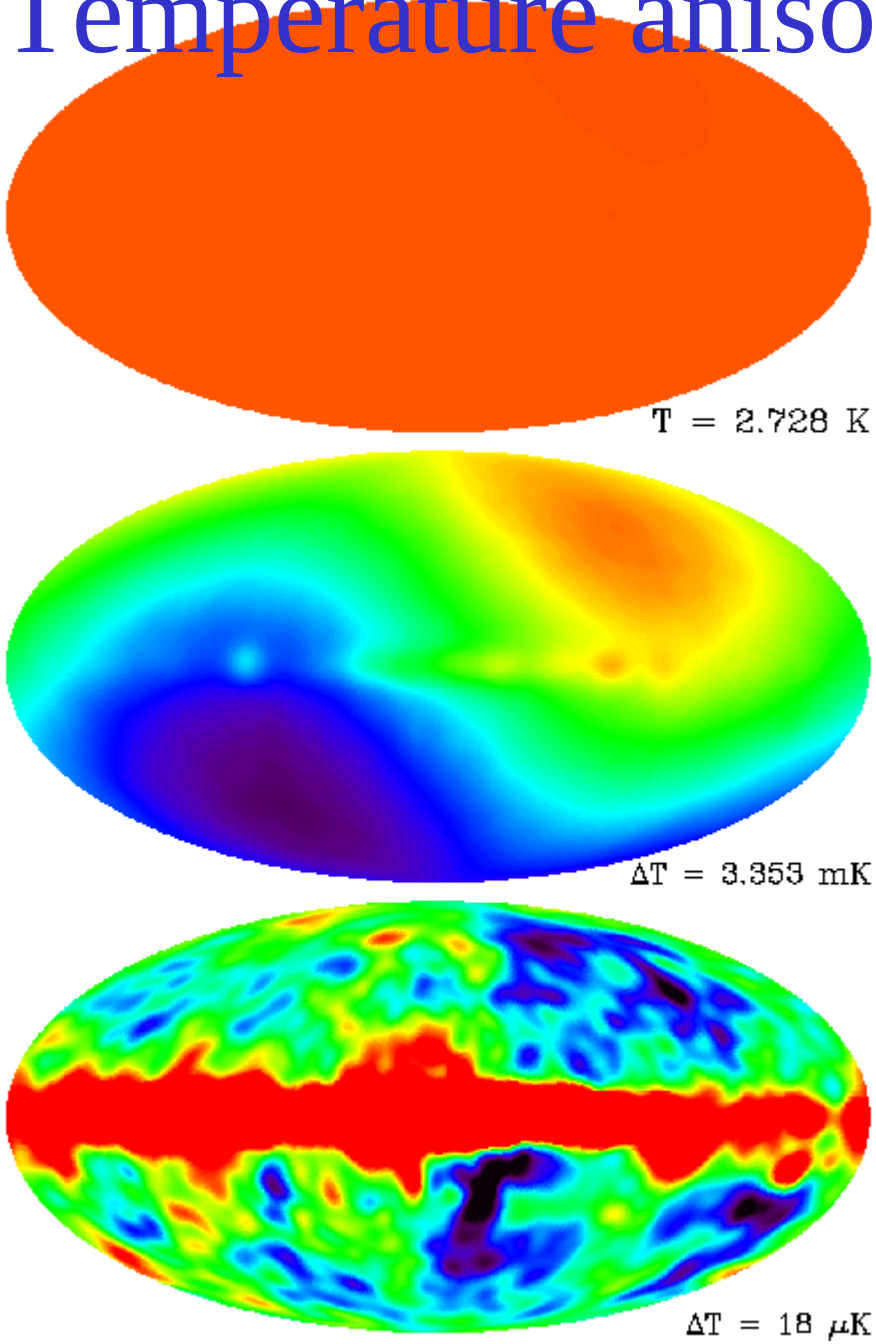
COBE (1990)

Complete photon spectrum

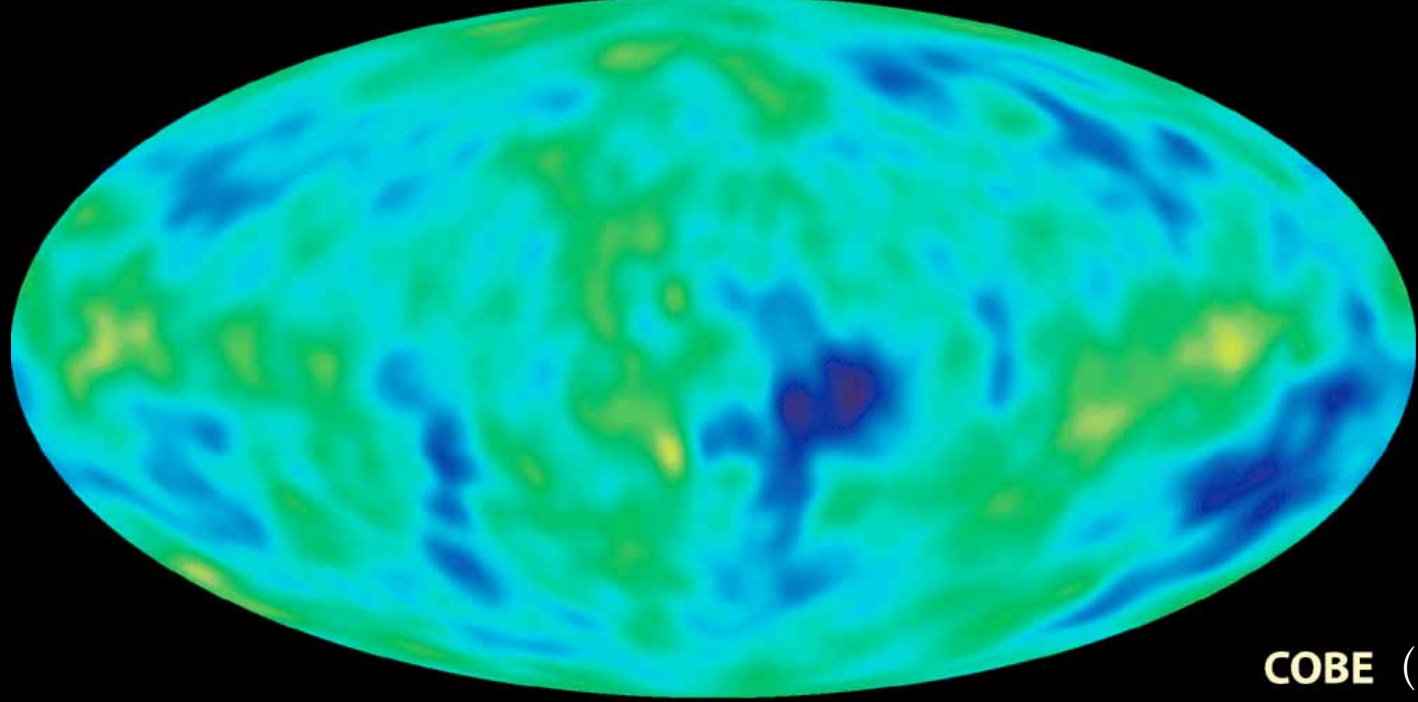


CMB Temperature anisotropies

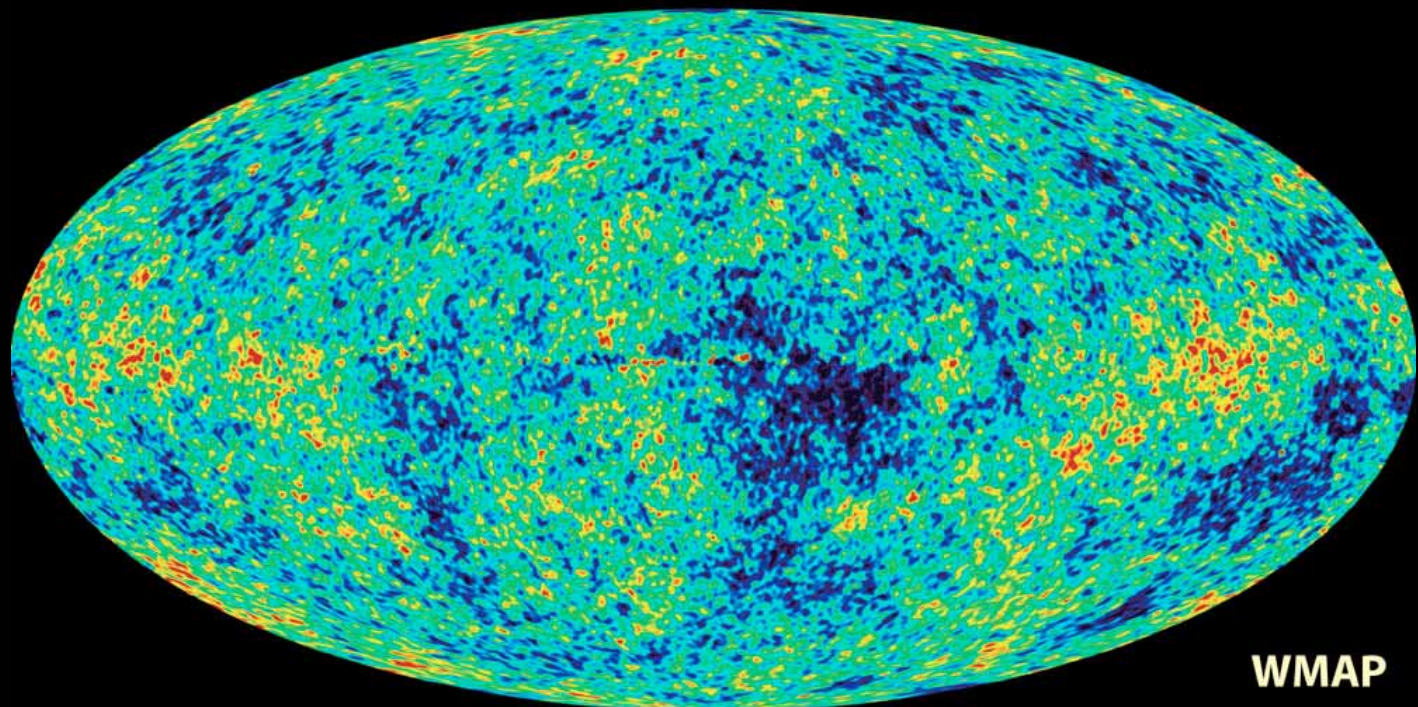
Smoot et al (1992)



COBE (1992)

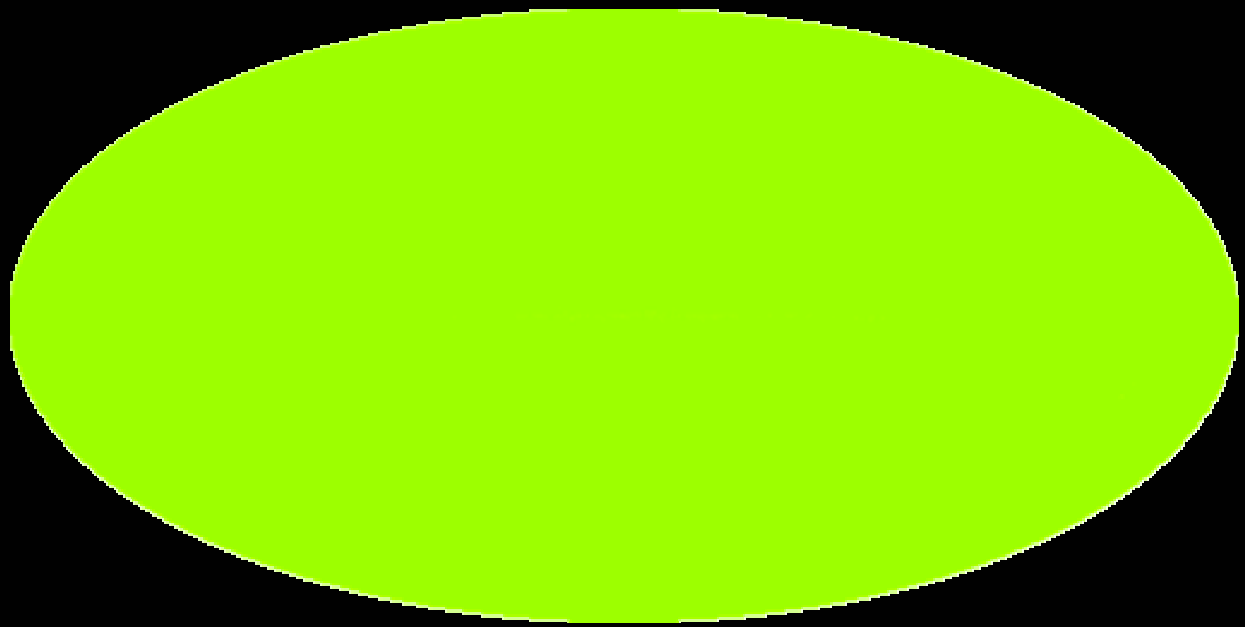


COBE (1992)



WMAP (2004)

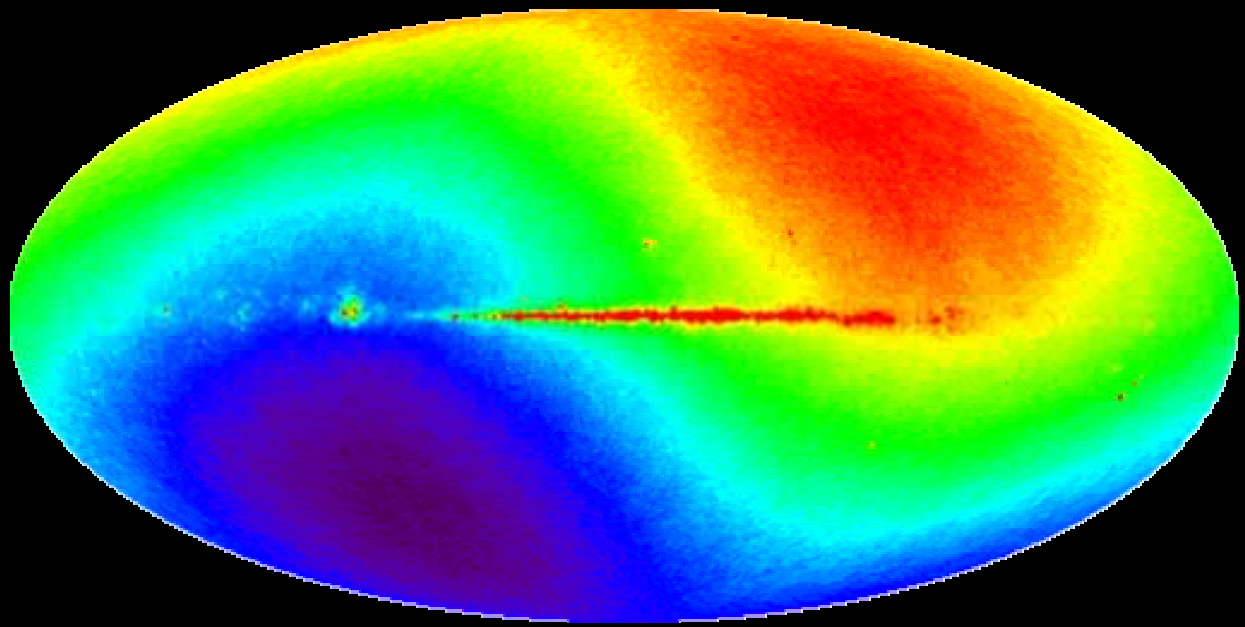
CMB Complete sky



isotropic

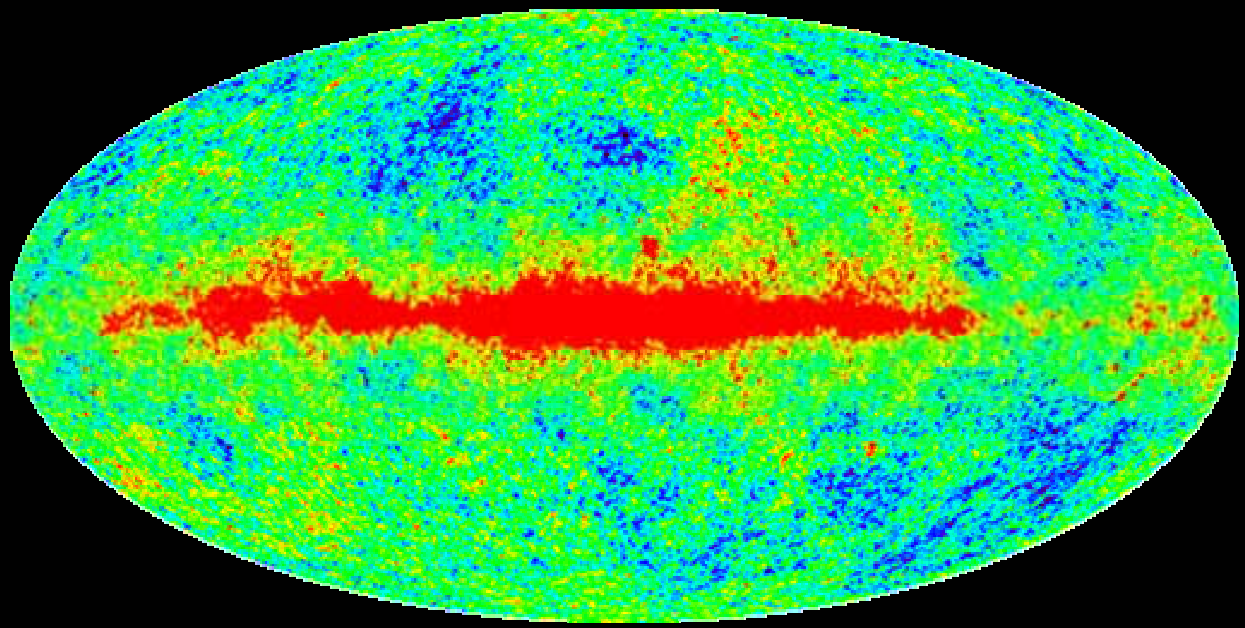
2.725 K

δ T/T ~10^{-3} level



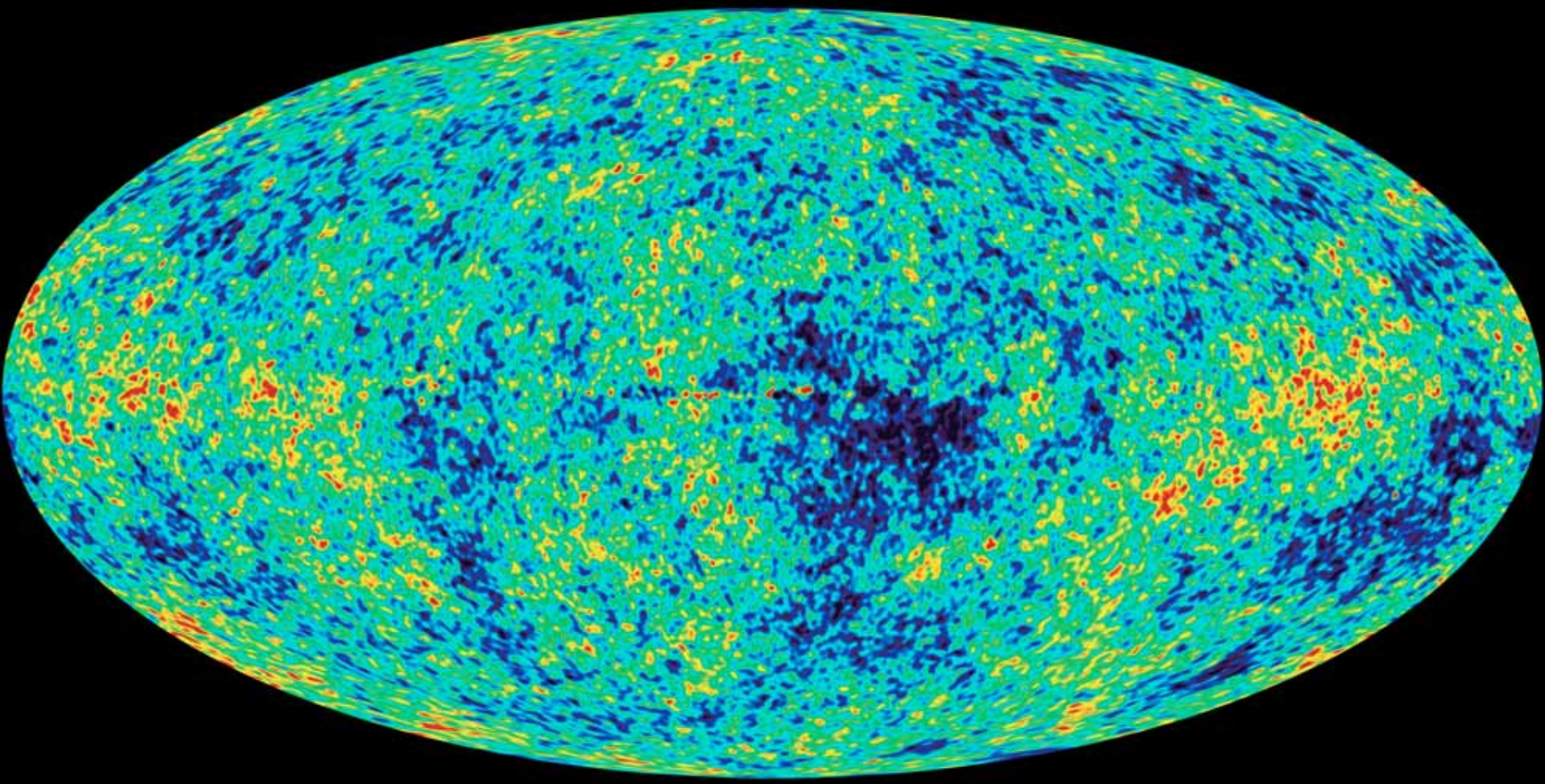
Dipole: perhaps due to our motion relative to CMB rest frame

δ T/T ~10^{-5} level



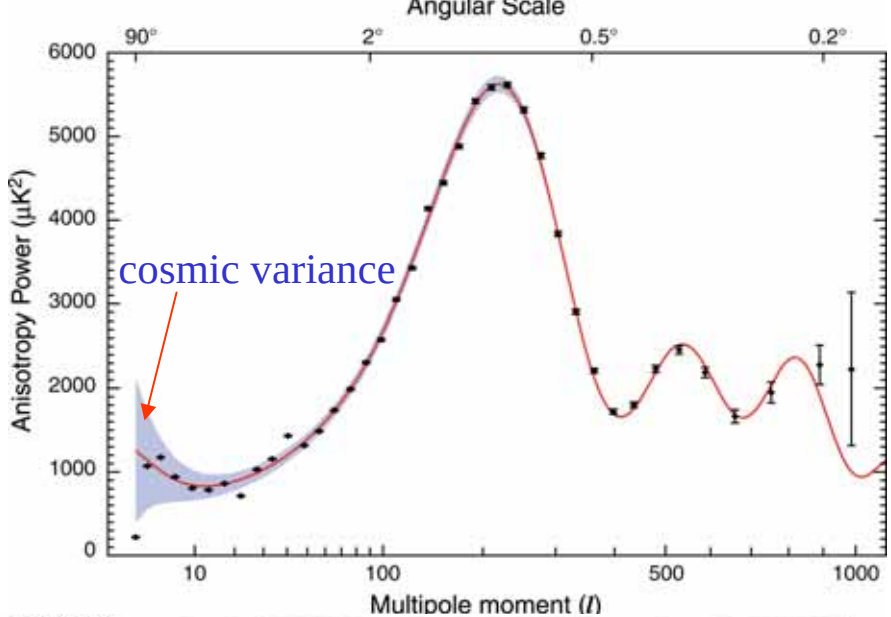
WMAP Satellite

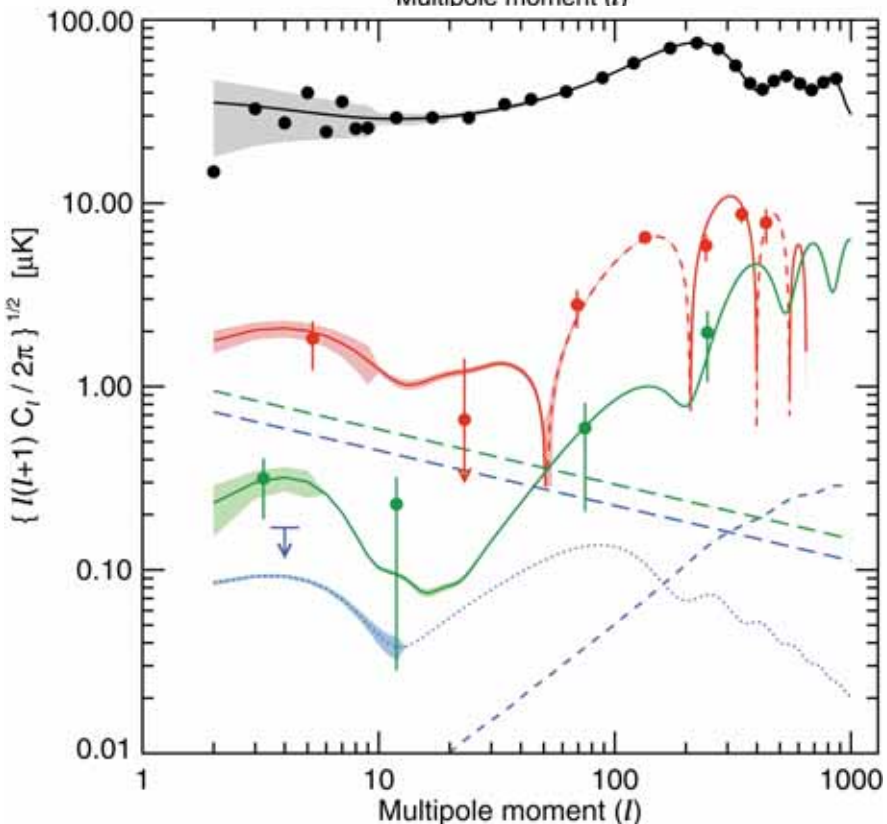
WMAP



WMAP -2006

Temperature-polarization anisotropies



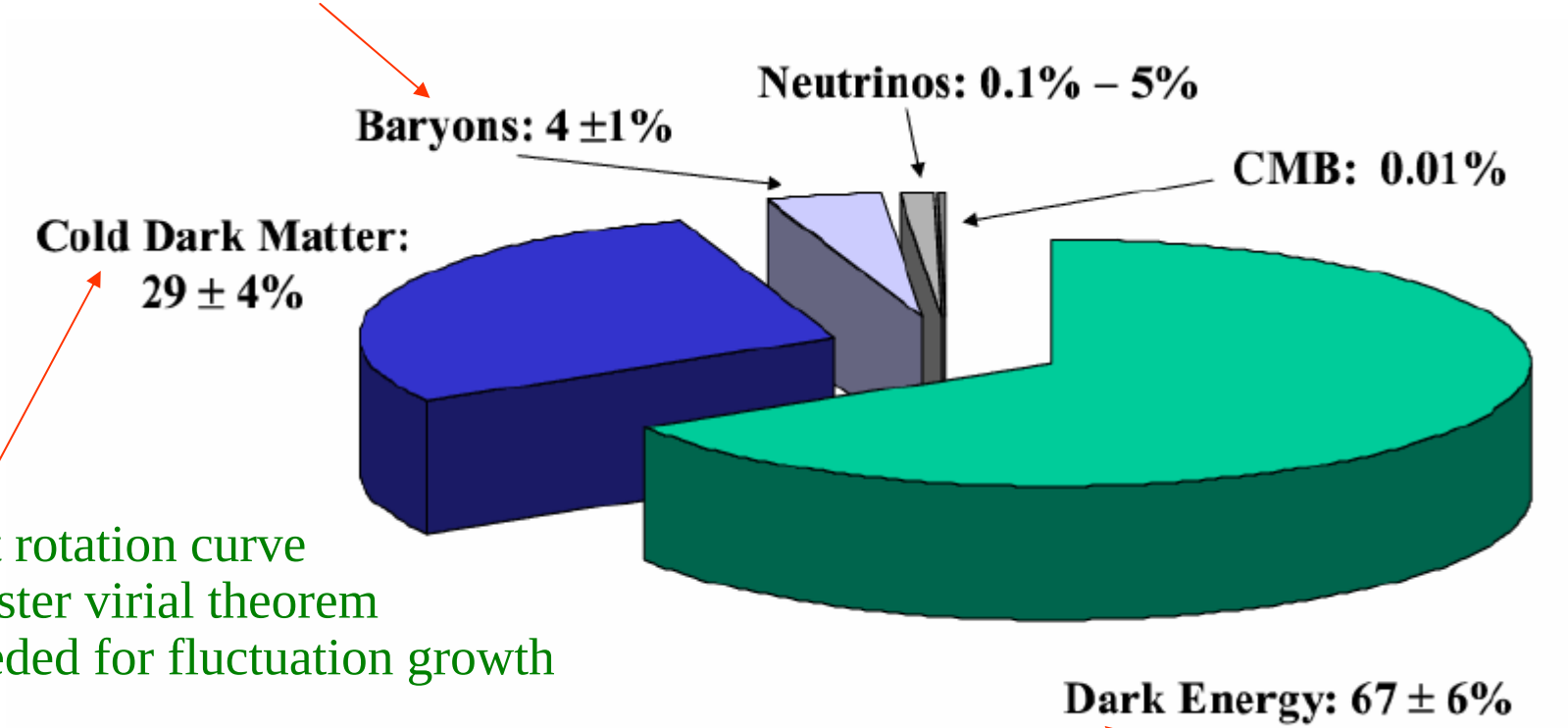


6. Amount of matter

- Minimum amount of the baryons observed.
- The rotation curve of spiral galaxies, and the virial theorem in cluster of galaxies indicate presence of non-luminous dark matter (DM).
- Recent observational and theoretical studies show presence of unclustered dark energy (DE) driving the universe accelerate.

Matter contents

Only part of it is luminous

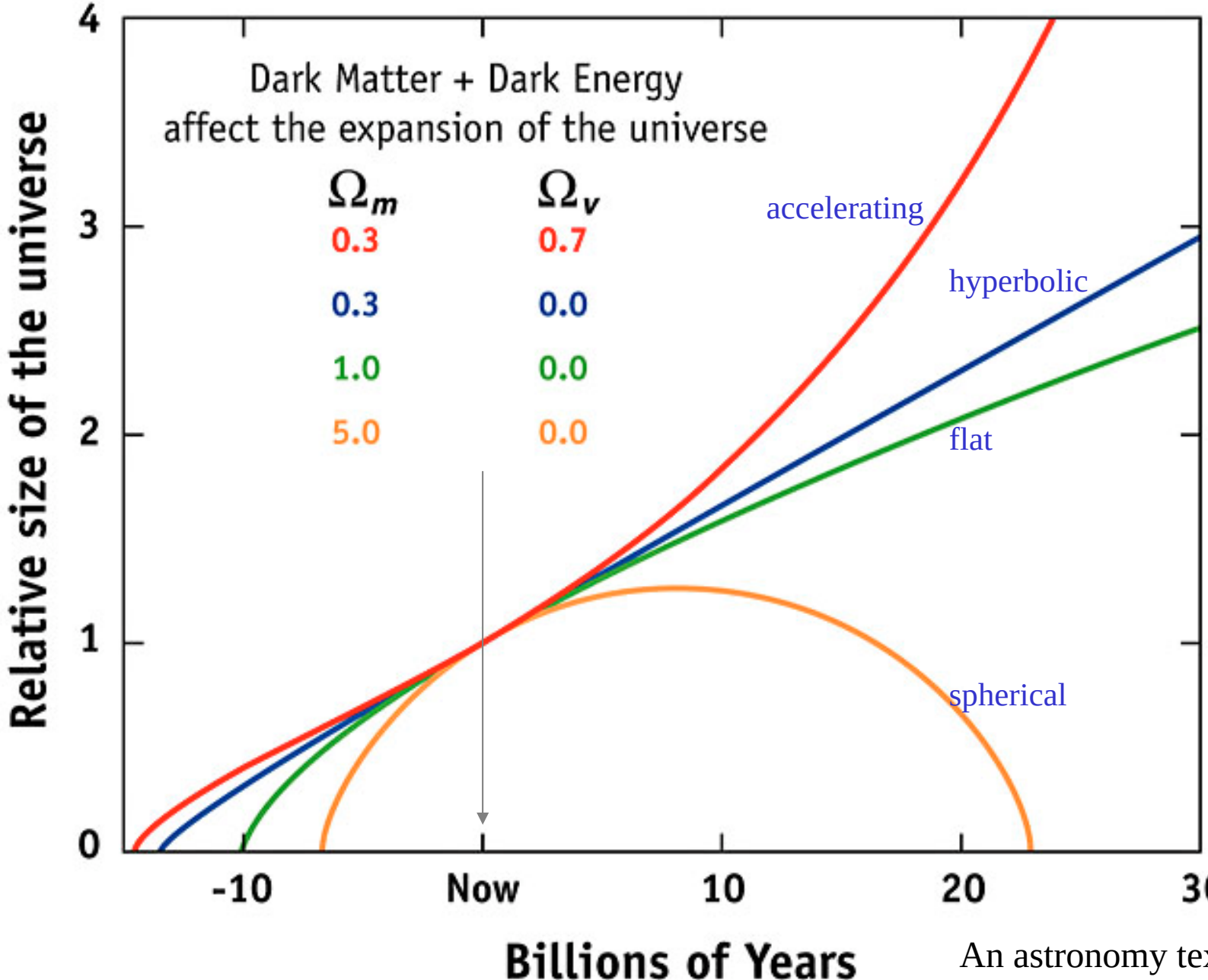


1. Flat rotation curve
2. Cluster virial theorem
3. Needed for fluctuation growth

Present acceleration

Freeman and Turner, astro-ph/0308418 (2003)

Expansion of the Universe



An astronomy textbook

7. Ages

- Age estimation of the globular clusters reduced by ~15%
- Age of the world model increased due to the acceleration.
- The proximity of the age of the world model and the age of the oldest stars is a big triumph of the standard world model.
- Recent estimation:

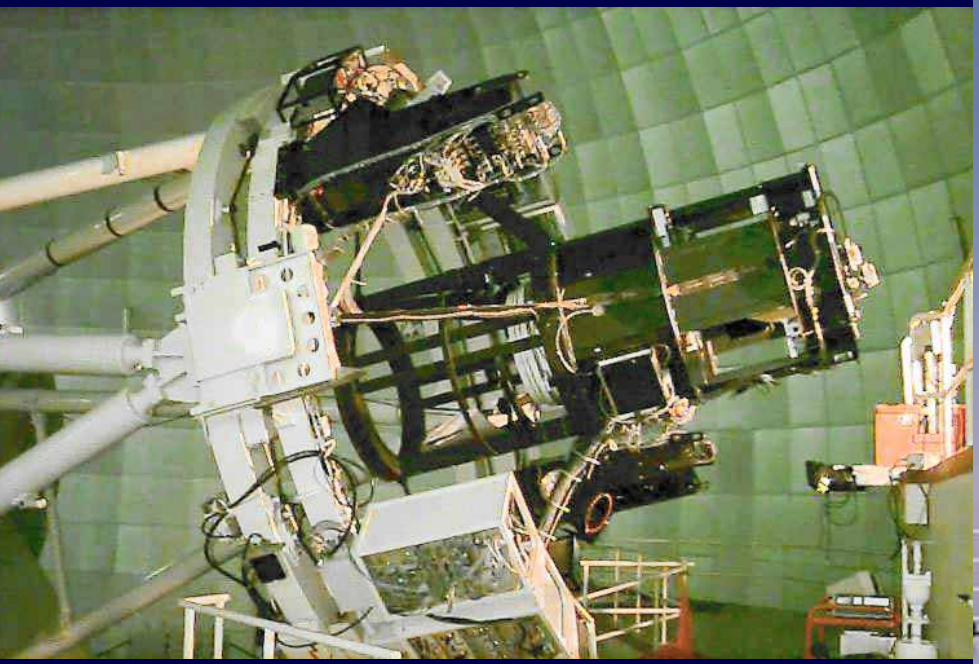
$$t = 13.7 \pm 0.2 \text{ Gyr} \quad \text{(WMAP)}$$

8. Galaxy clustering

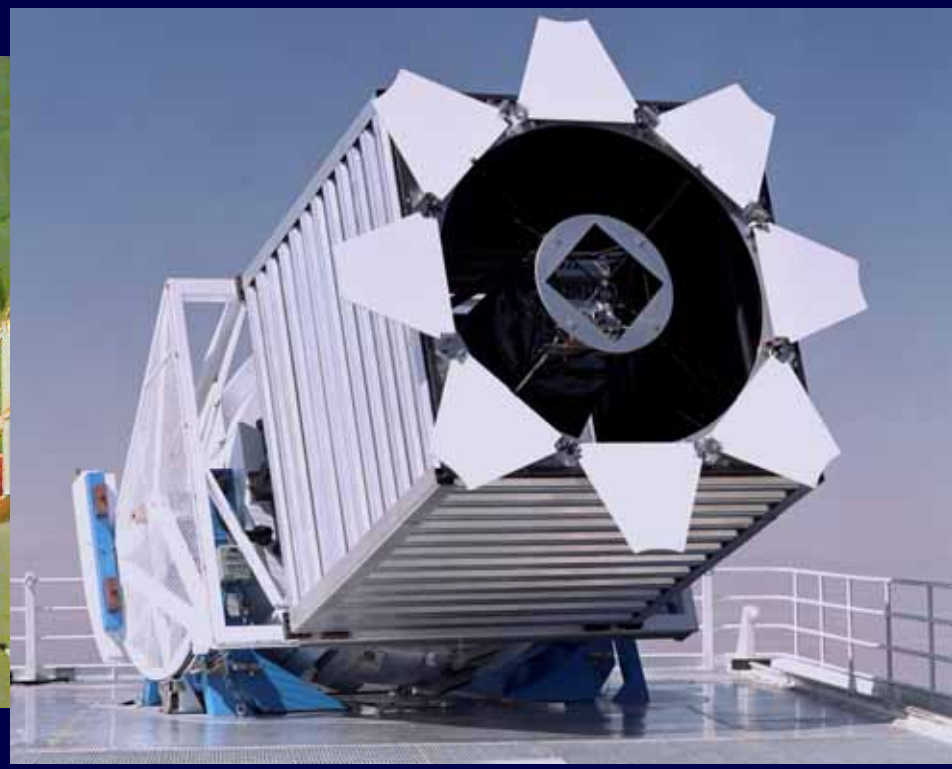
- Statistical patterns of the large-scale distributions of the observed (luminous) and gravitating (causing radial velocity) matter.
- Requires presence of dark matter in galactic and cluster scales.
- Spectrum is consistent with the Harrison-Zel'dovich one.

Large-scale structure

- Spatial distribution of galaxies

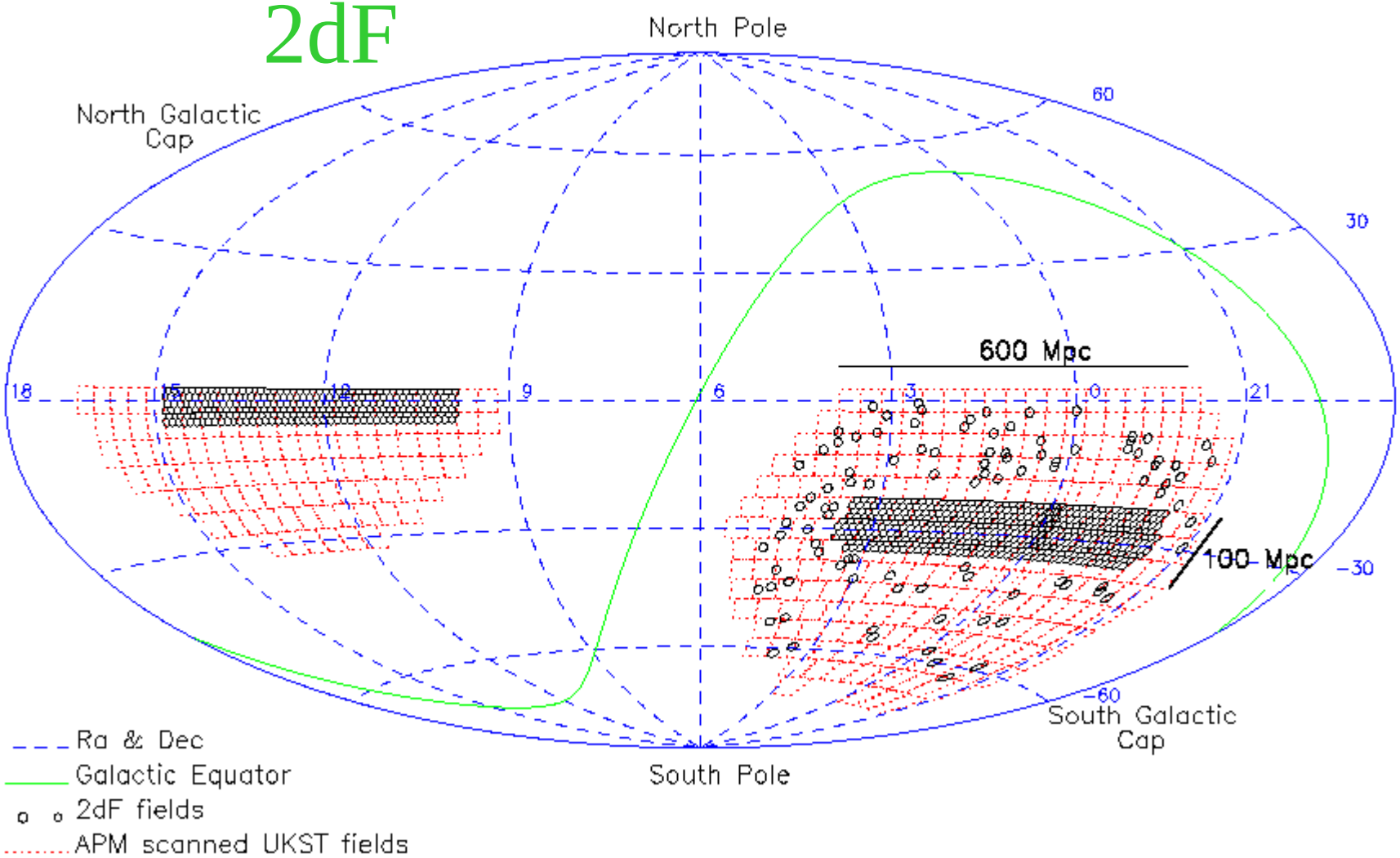


2dF (3.9m)



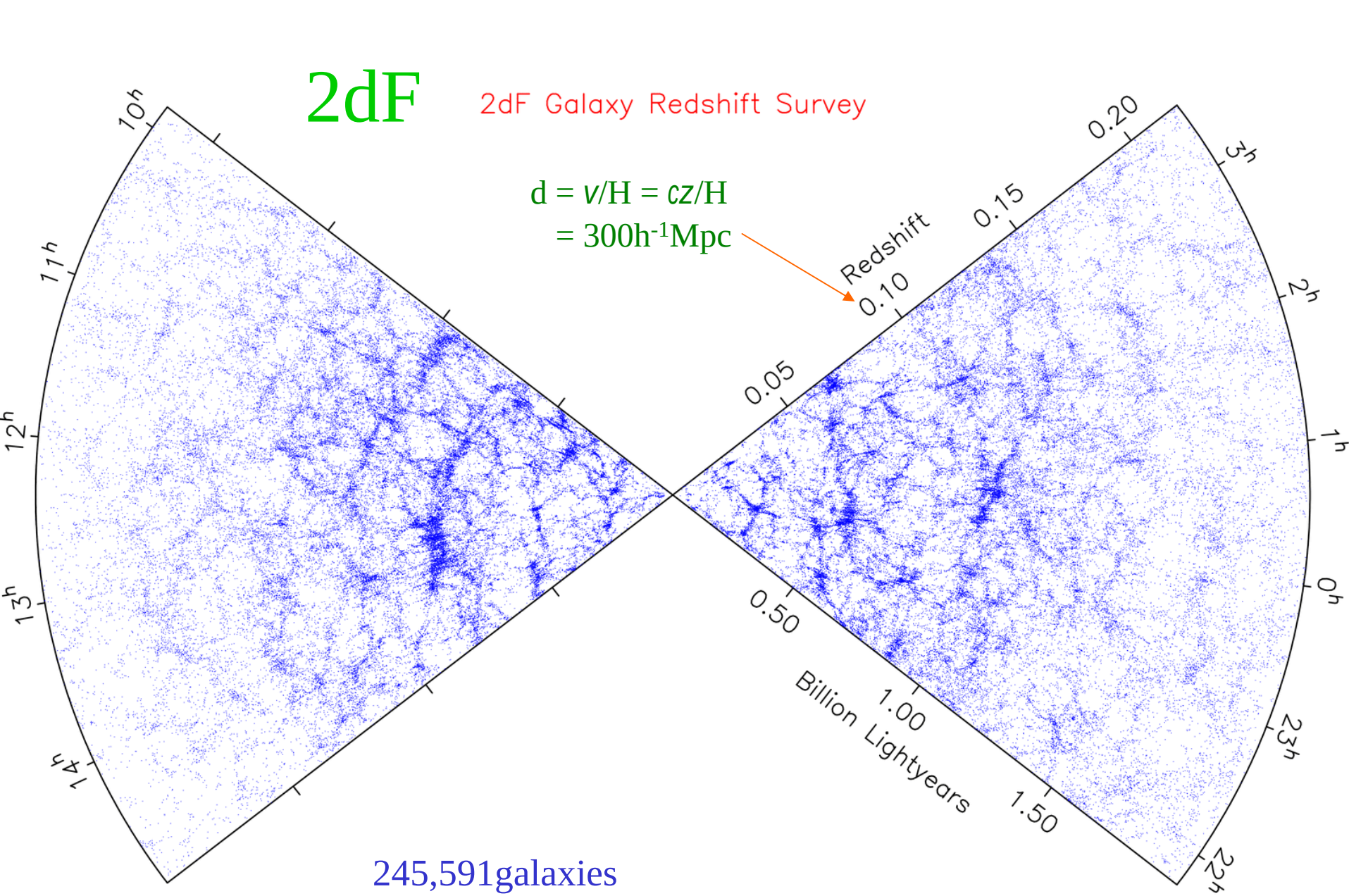
SDSS (2.5m)

2dF



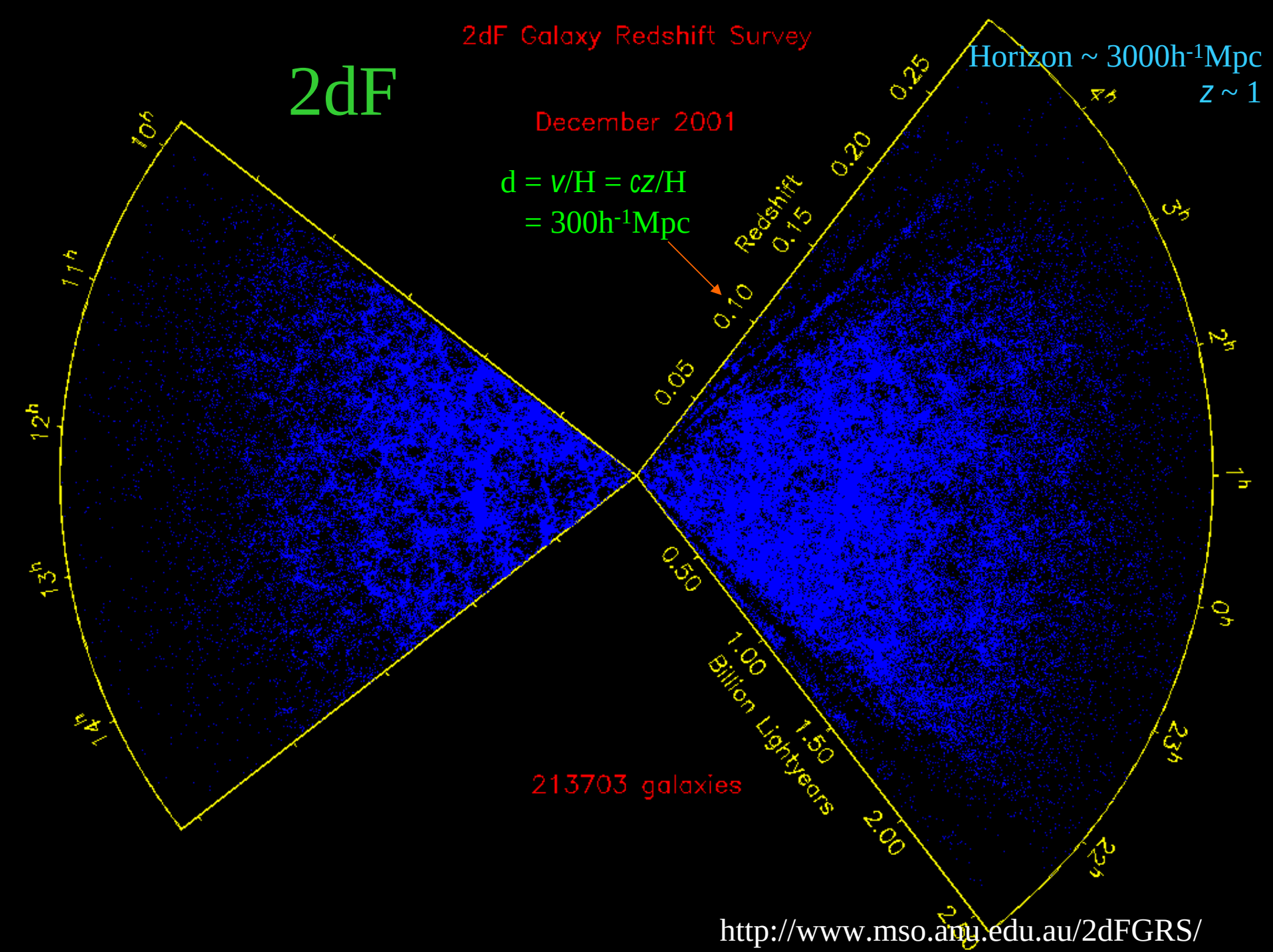
2dF Observed regions

http://www.mso.anu.edu.au/2dFGRS/

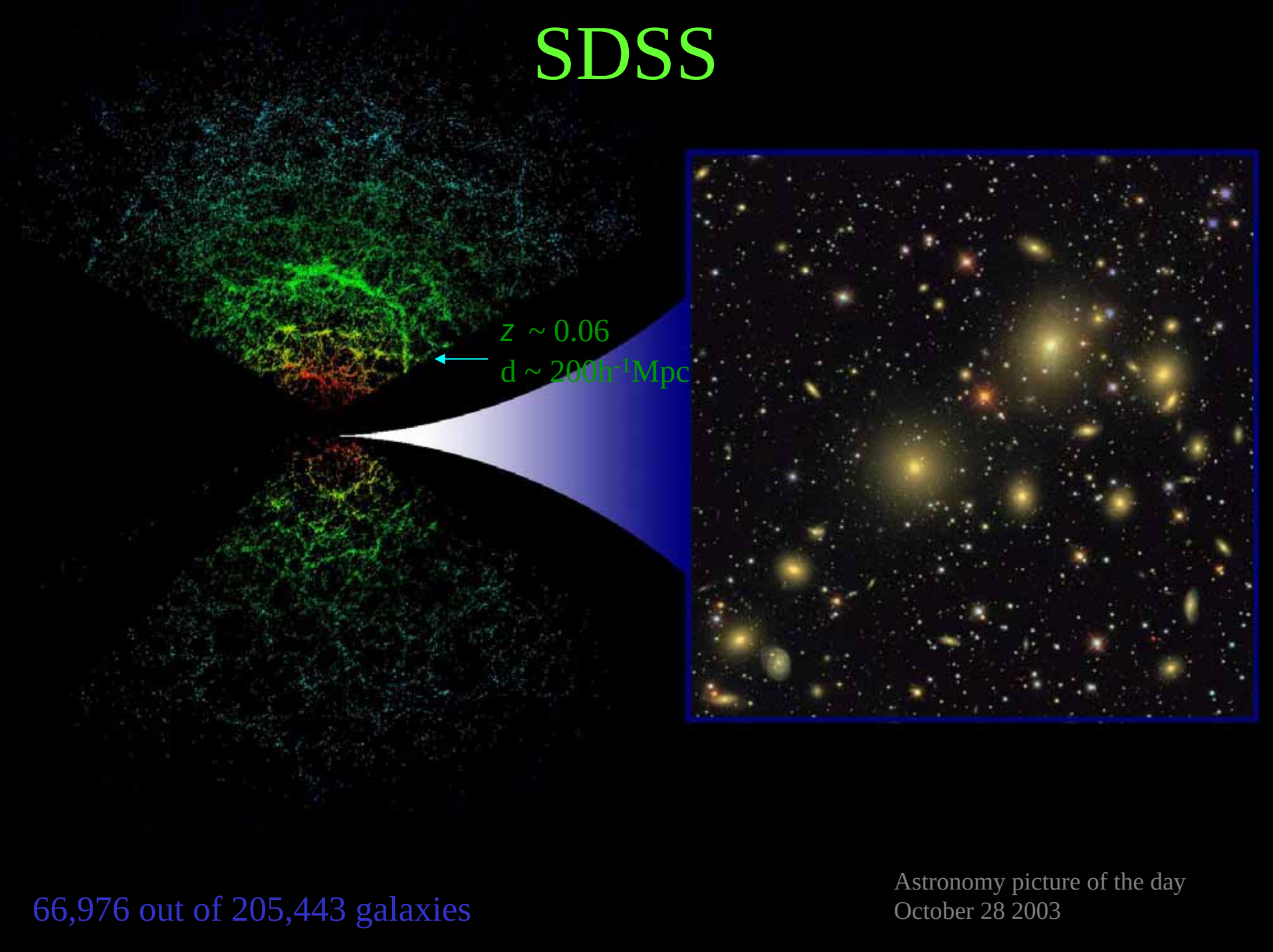


245,591galaxies
Limiting magnitude : 19.45

http://www.mso.anu.edu.au/2dFGRS/


2dF Galaxy Redshift Survey
2dF
December 2001
d = v/H = cz/H
= 300h-1Mpc
Horizon ~ 3000h-1Mpc
z ~ 1
Redshift
0.05
0.10
0.15
0.20
0.25
0.50
1.00
1.50
2.00
Billion Lightyears
213703 galaxies
http://www.mso.anu.edu.au/2dFGRS/

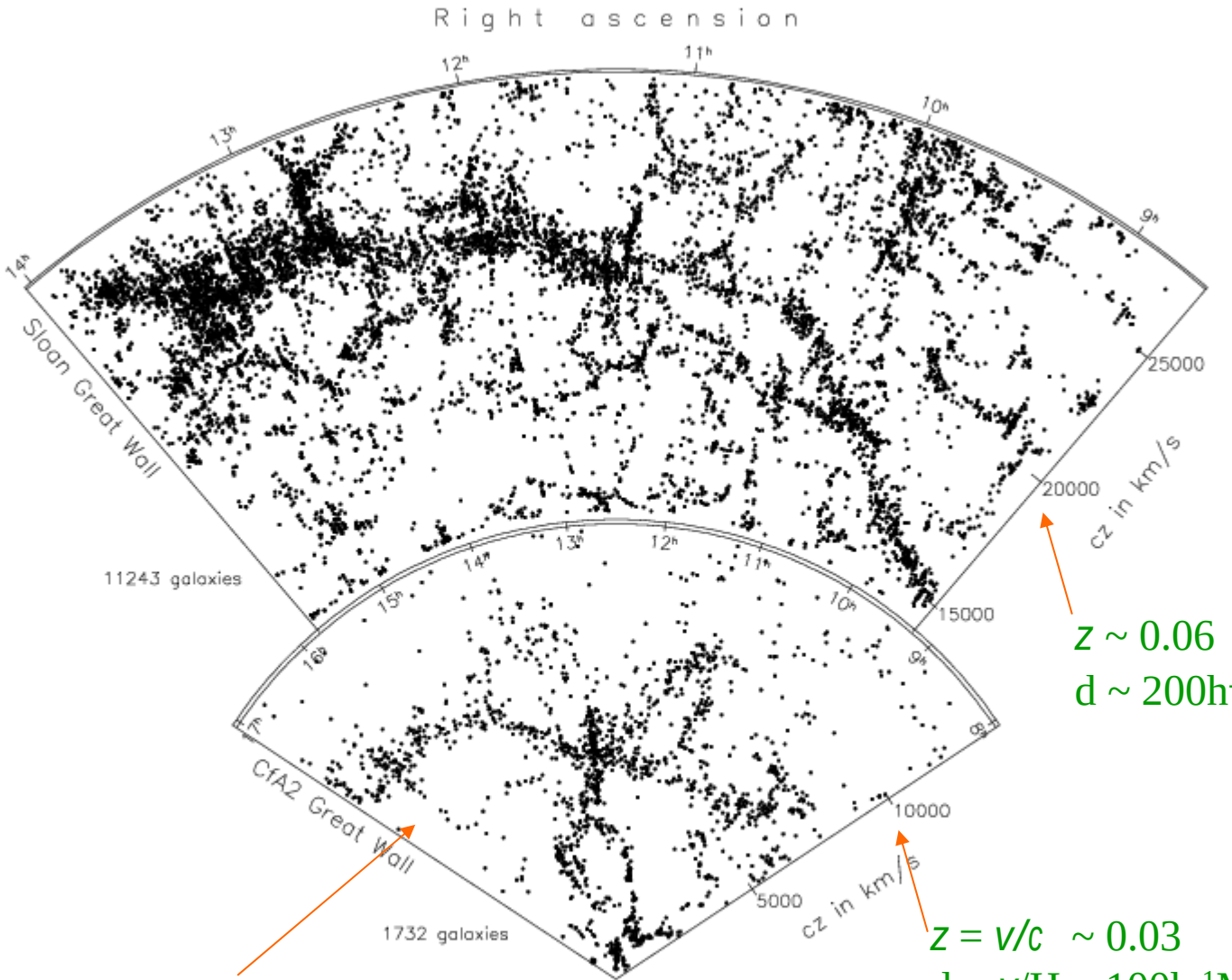
SDSS



66,976 out of 205,443 galaxies

Astronomy picture of the day
October 28 2003

SDSS

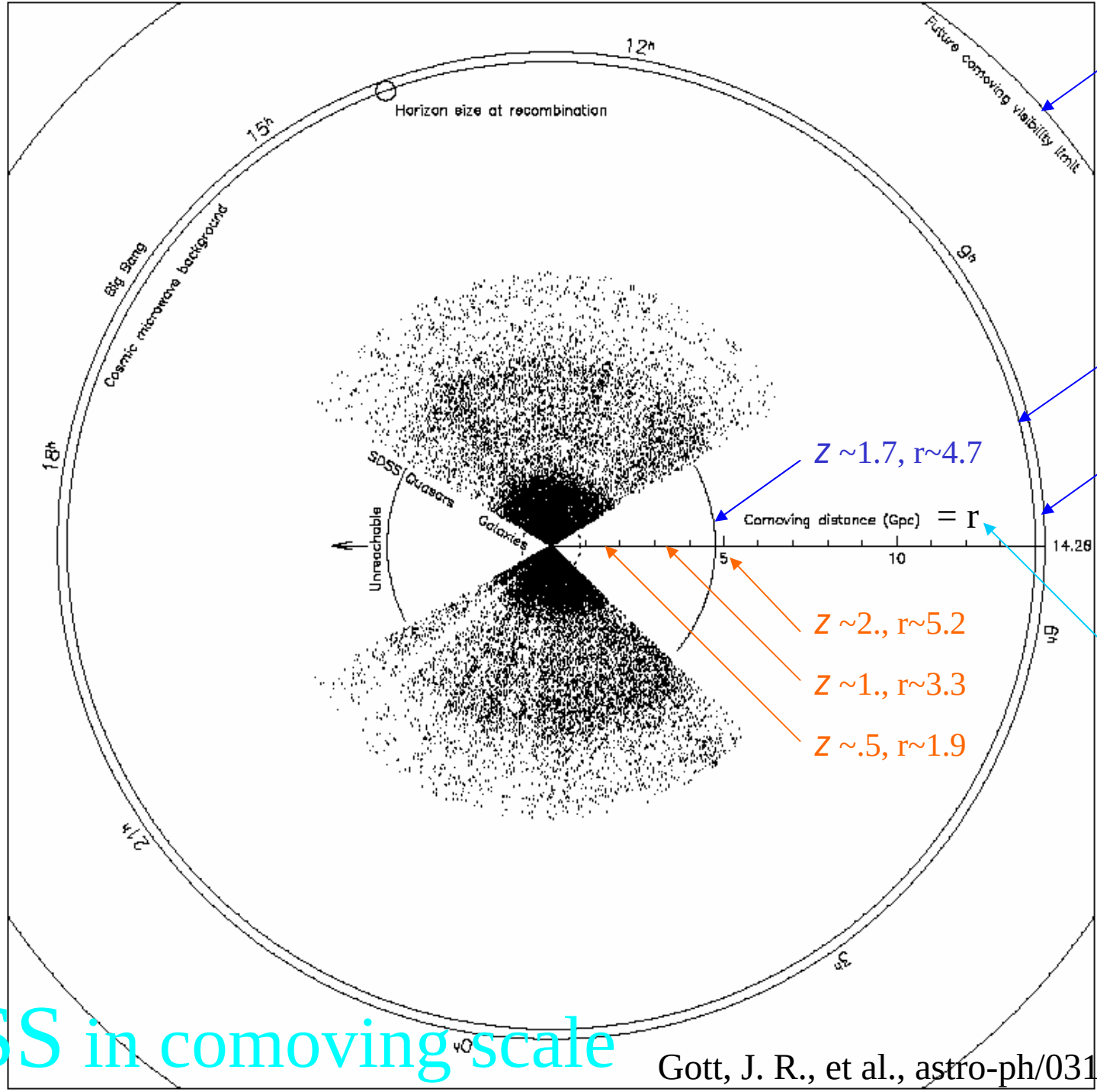


$z \sim 0.06$
$d \sim 200h^{-1}$Mpc

$z = v/c \sim 0.03$
$d = v/H \sim 100h^{-1}$Mpc

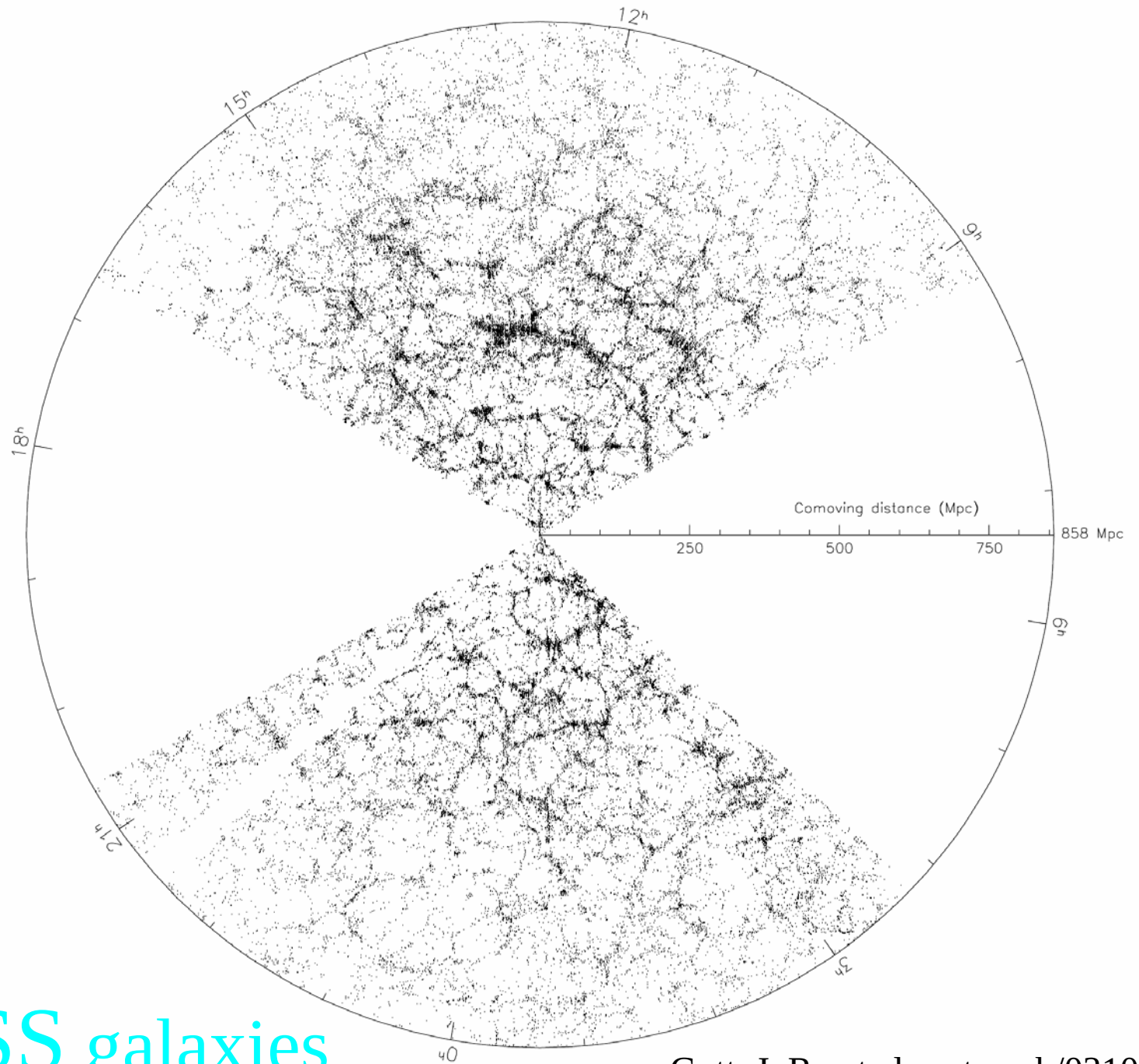
de Lapparent *etal.* (1986)

http://www.sdss.org/



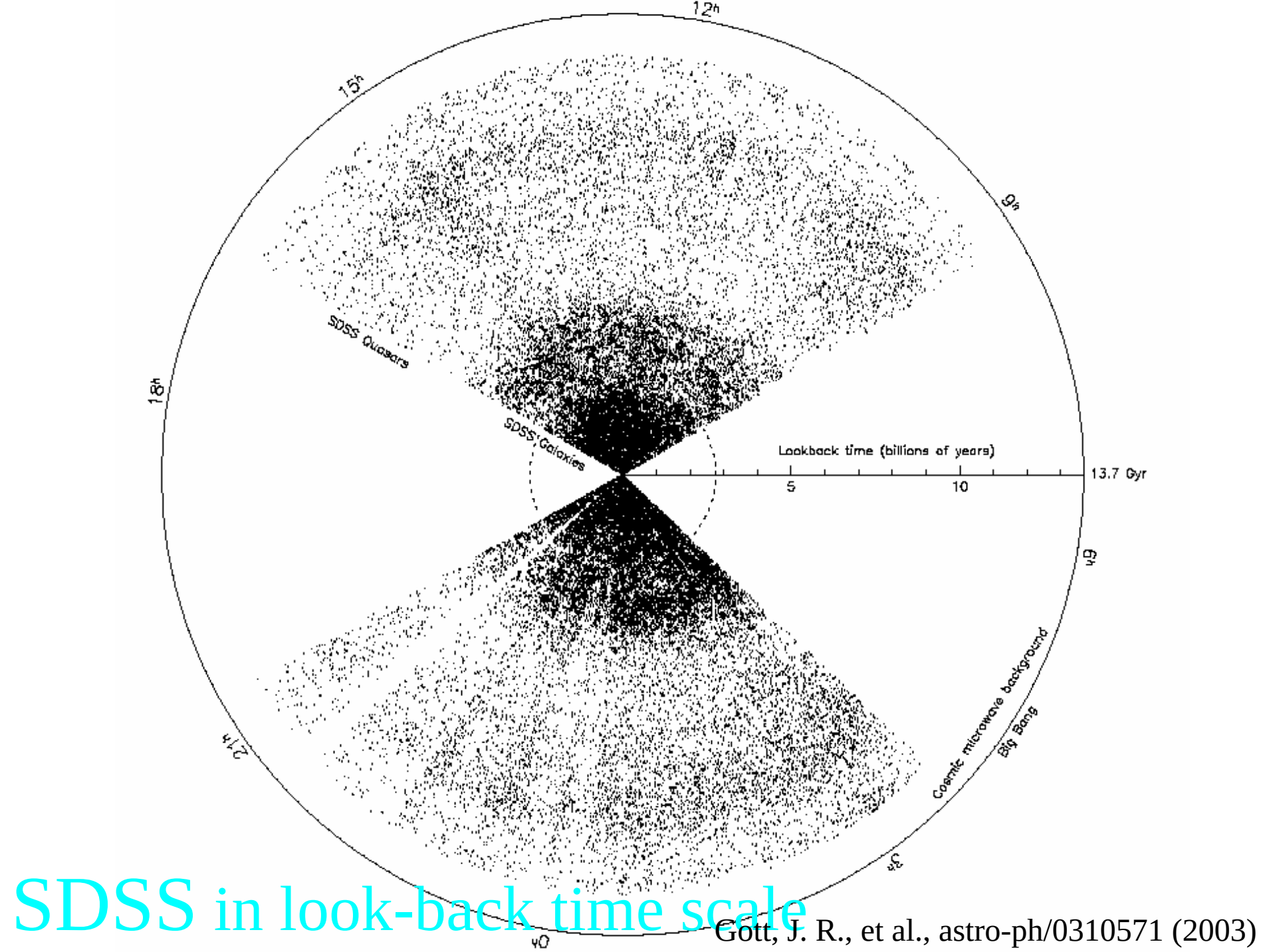
SDSS in comoving scale

Gott, J. R., et al., astro-ph/0310571 (2003)



SDSS galaxies

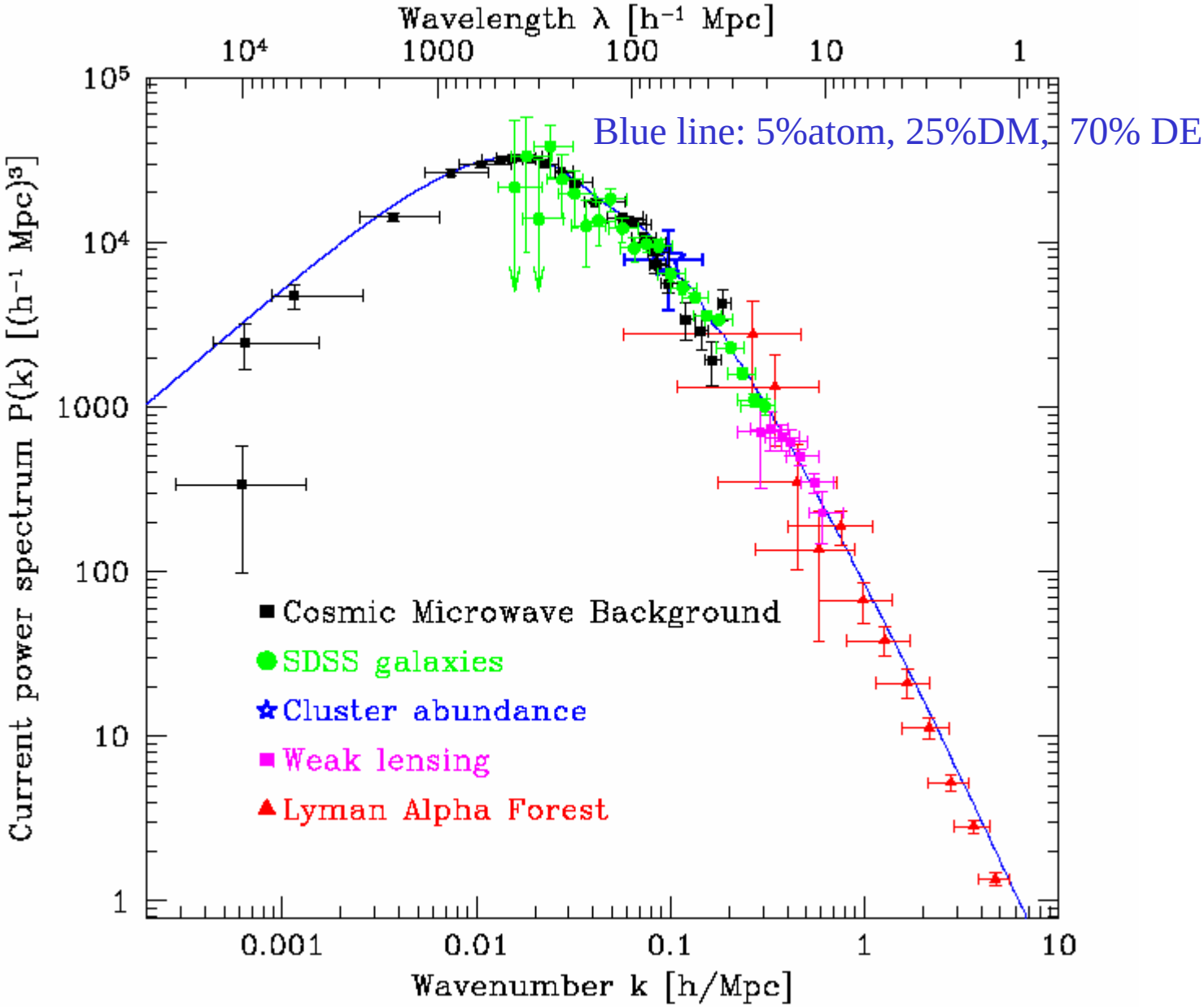
Gott, J. R., et al., astro-ph/0310571 (2003)



SDSS in look-back time scale

Gott, J. R., et al., astro-ph/0310571 (2003)

Density power spectrum



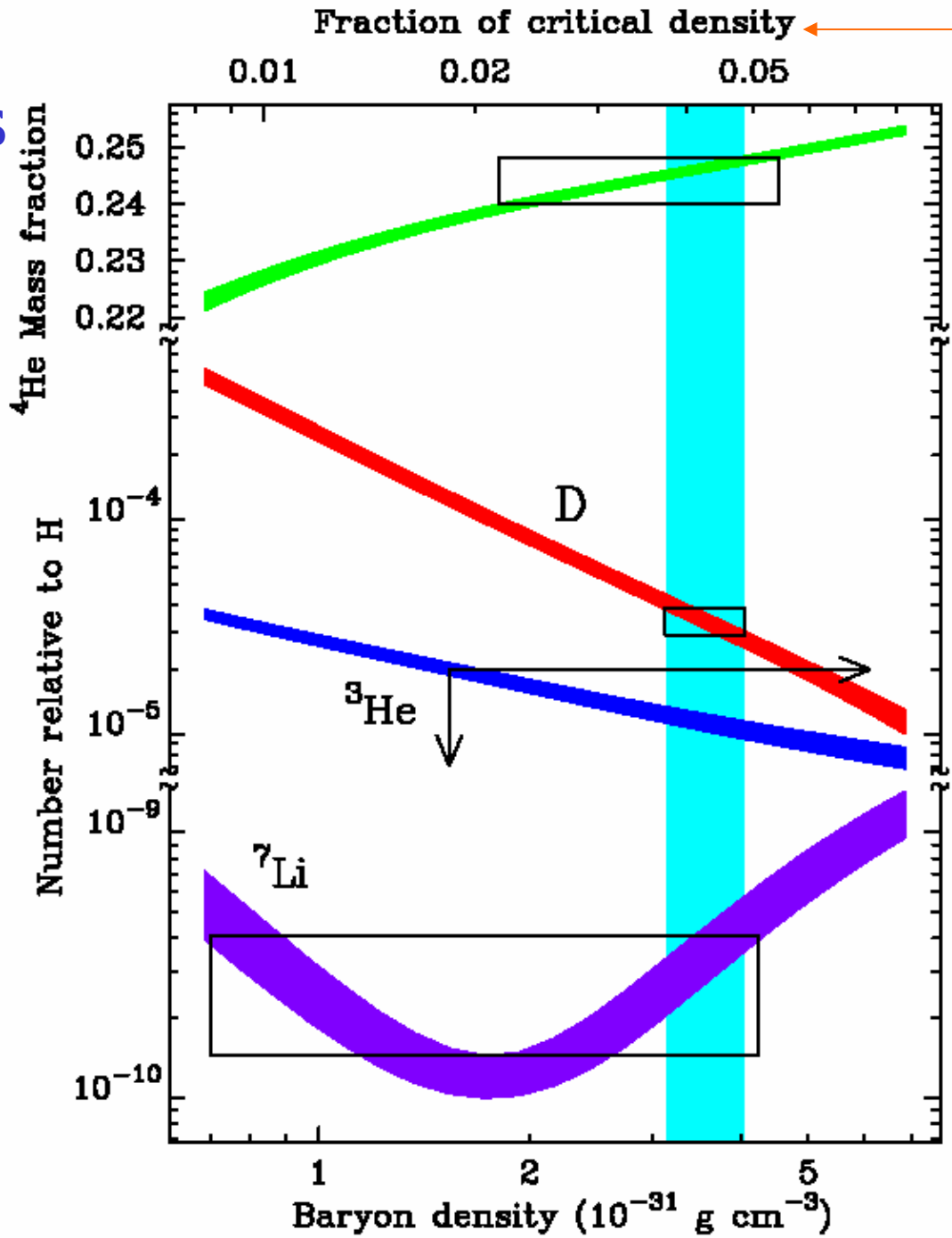
Tegmark, M., et al, astro-ph/0207047 (2002)

9. Element abundances

We have theoretical range of the abundances of the Hydrogen, Helium and Litium which are consistent with observation.

H, D, ^{3}He, ^{4}He, ^{7}Li

Primordial Nucleosynthesis



Freeman and Turner (2003)

10. Matter vs. antimatter

- Apparently the observed universe is mainly composed of the matter instead of the antimatter:

$$n_{\text{Baryon}}/n_{\text{Photon}} \sim 10^{-10}$$

11. Existence of observers

One should not forget possible significance of our presence in our observed patch in the universe. Apparently one is forbidden to observe the existence of other possible patches where the presence of the observer is not allowed. This does not mean that such patches are not allowed.

Anthropic principle:

> "What we can expect to observe must be restricted by the conditions necessary for our presence as observers. (Although our situation is not necessarily *central*, it is inevitably privileged to some extent.)"
>
> Brandon Carter (1974)

> "The world is the way it is, at least in part, because otherwise there would be no one to ask why it is the way it is."
>
> S. Weinberg (1989)

For a balanced view,

"It is much better to find a simple physical resolution of the problem rather than speculate that we can live only in the universes where the problem does not exist. There is always a risk that the anthropic principle does not cure the problem, but acts like a painkiller."

A. Linde (2002)

Still,

"The conditions necessary for human existence impose narrow limits on the design of the universe."

E. Harrison (1992)

Bright daylight problem

"Considering the darkness of the sky in average place in the universe, what is rather ironic is our special location nearby a star, thus having a bright daylight. Here, the anthropic argument provide an answer: being organisms living on the surface of a planet fatally depending on the solar energy, it is necessary that we can be found only nearby a star; i.e., otherwise, there would be no one like us who can raise the question."

JH

Some Issues

"There is a widespread conviction that the new teachings of astronomy and physical science are destined to produce an immense change on our outlook on the universe as a whole, and on our views as to the significance of human life. The question at issue is ultimately one for philosophic discussions."

Sir James Jeans (1932)

http://bh.knu.ac.kr/~jchan/cosmology.ps

Before the big bang?

"Nothing can ever be created by divine power out of nothing."

Lucretius (~100-55 B.C.)

"First God made heaven and earth, …"

Genesis 1, The Bible

"What was God doing before the creation of the world? Some people say that before He made the Heaven and Earth, God prepared Gehenna (hell) for those who have the hardihood to inquire into such high matters. … There was no time before creation, and hence the question was not cogent. Simultaneously with time the world was made."

Saint Augustine (354-430)

"The universe is created with time, not in time."

J. D. Barrow (1999)

I believe it is rather a far-fetched interpretation. As we approach the singularity we are no longer able to depend on the classical gravity, and, I believe it is fair to say that, we do not have better suggestions yet.

"… danger of strongly believing in ideas not confirmed by observation, … without this confirmation we lose the only way we can distinguish science from metaphysics."

M. R. Ribeiro, etal (1998)

"Cosmologists are often in error, but never in doubt."

L. D. Landau (1908-1968)

Boundary of the universe?

"Learn, therefore, that *the universe is not bounded in any direction*. If it were, it would necessarily have a limit somewhere. But clearly a thing cannot have a limit unless there is something outside to limit it, … Since you must admit that there is nothing outside the universe, it can have no limit and is accordingly without end or measure."

Lucretius (~ 100-55 B.C.)

Expanding Friedmann world model has a finite horizon, the light travel distance during the age of the universe, thus about 14Gly. In this world model we do not need to assume anything which encompass beyond the horizon from the outset.

"In the search for truth there are certain questions that are not important. Of what material is the universe constructed? Is the universe eternal? Are there limits or not to the universe? … If a man were to postpone his search and practice for Enlightenment until such questions were solved, he would die before he found the path."

Gautama Buddha (563-483 B.C.)

"Socrates didn't spend his time discussing the nature of everything as most others did, wondering about what the experts call the *kosmos* and the reasons for all the things in the sky necessarily coming about as they do; on the contrary he pointed out the foolishness of those who were concerned with such matters."

Xenophon, cited in M. R. Wright (1995)

What's beyond the horizon, anyway?

What's beyond the present horizon is, by definition, beyond our recognition at present.

"When our models give predictions of the nature of the Universe on a larger scale than the Hubble radius, these are strictly unverifiable, however appealing they may be."

G. F. R. Ellis (1993)

"Because we wish to talk about regions we cannot directly influence or experiment on, our theory is at the mercy of the assumptions we make."

G. F. R. Ellis (1975)

"When a feature of a model is ascertained through imposition rather than by experimental or observational check it is unscientific because it is *only* based on personal choices. In other words, a certainty achieved that way becomes a dogma."

M. R. Ribeiro, etal (1998)

Future of the universe

"Definite predictions may be made for finite (though very large) intervals of time only, as well as in other branches of science. … we see that the future of our Universe may be not simply *very* complicated but even *infinitely* complicated."

A. A. Starobinsky (2000)

"The charm and importance of a study of the heavens was matched only by the uncertainty of the knowledge produced."

Aristotle (384-322 B.C.)

The ultimate question?

“On the ultimate origination of things: why there is a world at all? Why is there something rather than nothing?”

Gottfried Wilhelm Leibniz (1646-1716)

“I wonder at the existence of the world: how extraordinary that anything should exist, or, how extraordinary that the world should exist.”

Ludwig Wittgenstein (1889-1951)

“Why is there any Being at all - why not far rather Nothing?”

Martin Heidegger (1889-1976)

These are philosophic questions.

More tractable ones, perhaps

"Where do we come from? What are we? Where are we going?"

Paul Gauguin (1897)

These must belong to the most profound questions raised by humankind, especially the middle one.

Meanwhile, we also have

"It is better to inquire about 'light' things, finding some truth, than keeping to wonder about the 'maximal questions' without reaching anything."

Galileo Galilei (1564-1642)

"Where do we come from? What are we? Where are we going?"

Paul Gauguin (1897)

Pointlessness

"The more the universe seems comprehensible, the more it also seems pointless."

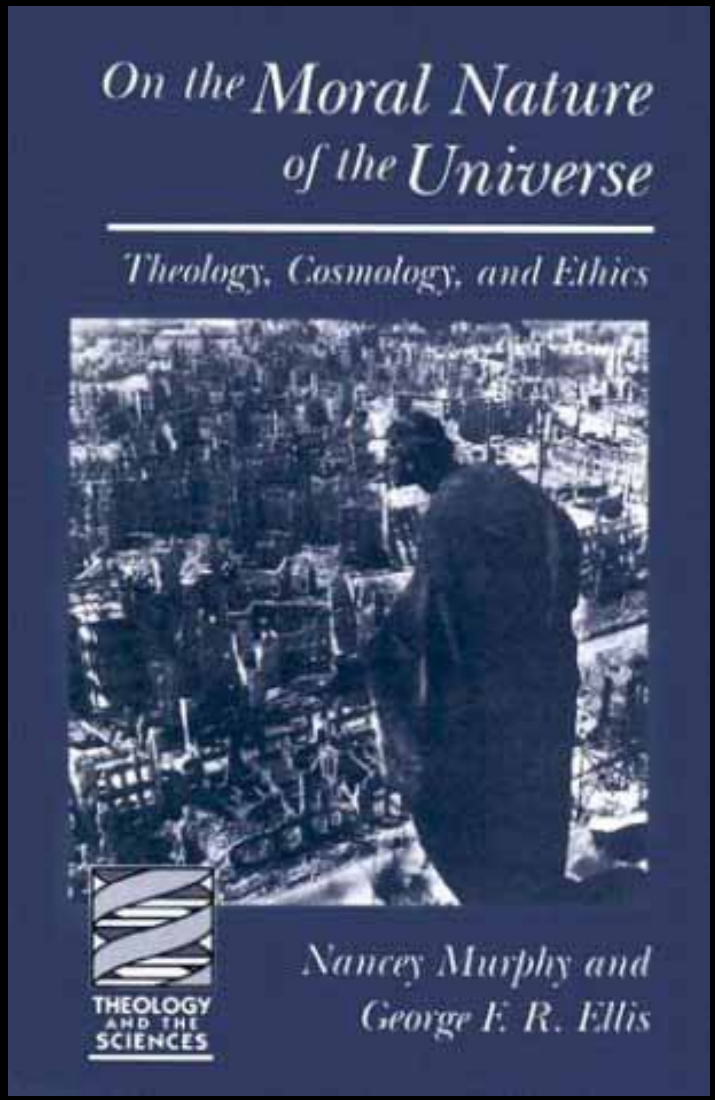
S. Weinberg (1977)

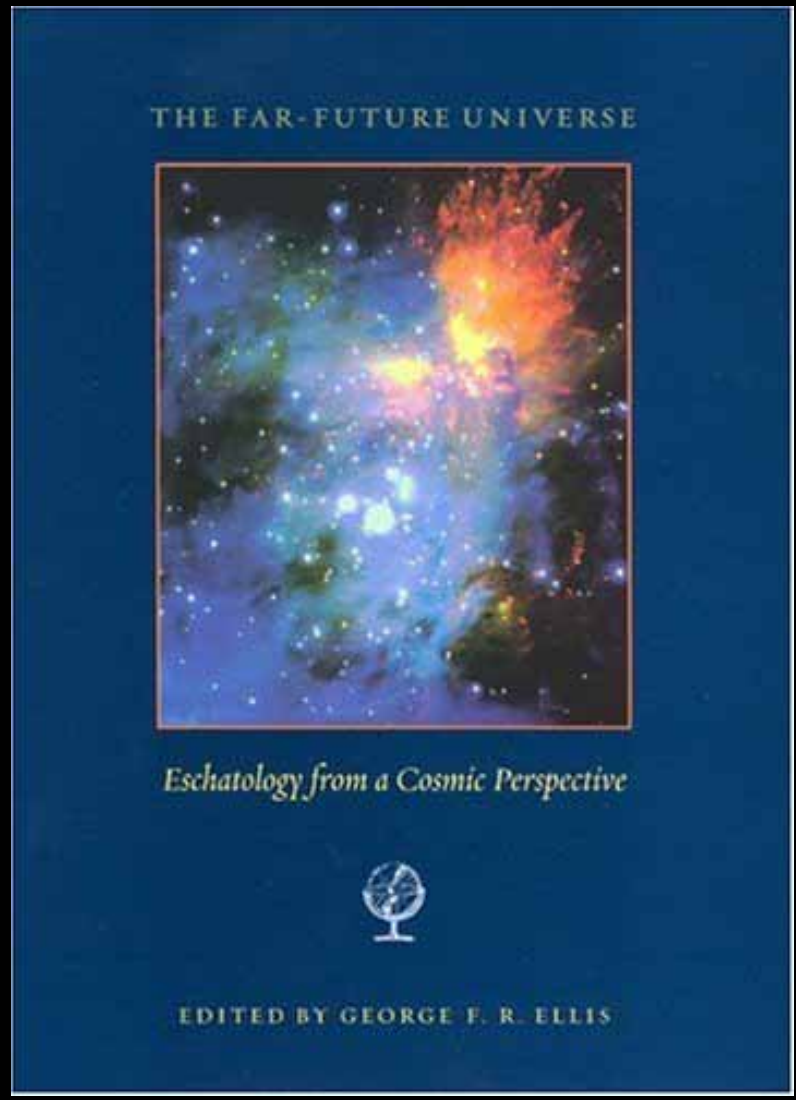
It seems to me, physics is not the right tool if one is interested in the 'point (purpose or meaning) of the universe'. Although, modern sciences have been trying to avoid the term 'purpose' intentionally, still perhaps, Cosmo'bio'logy would provide better perspective on such a matter, not physical cosmology.

"Physical cosmology confines its attention to the 'how' of the universe and does not deal with the 'why'."

R. A. Alpher et al (2001)

All interesting fundamental questions are metaphysical ones then.





"Everything's got a moral, if only you can find it"

Lewis Carroll *"Alice's Adventures in Wonderland"* (1865)

"Wormholes? Baby universes? Infinite dimensional superspace of string theory? … it is ironic science, science that is not experimentally testable or resolvable even in principle … Its primary function is to keep us awestruck before the mystery of the cosmos. … Ironic cosmology will continue, of course, as long as we have poets as imaginative and ambitious as Hawking, Linde, Wheeler, … Their visions are both humbling, in that they show the limited scope of our empirical knowledge, and exhilarating, since they also testify to the limitlessness of human imagination. … But it is not science."

J. Horgan (1996) "The end of science:
Facing the limits of knowledge
in the twilight of the scientific age".

"cosmology itself, like all arts and sciences, is a construct of human intelligence, subject to social and linguistic conditioning and dubious means of communication."

M. R. Wright (1995)

In any case,

“It is open to every man to choose the direction of his striving;
and also every man may draw comfort from Lessing's fine saying,
that the search for truth is more precious than its possession”

Albert Einstein (1940)

Status and Prospect

“Prediction is very hard, particularly of the future.”

Neils Bohr (1885-1962)

Present status of cosmology

- Rapid development in observations

  CMB temperature-polarization anisotropies, large-scale distributions of galaxies, first structure formation

- Precision cosmology

  Possible determination of cosmological models and structure formation theories within few percent.

- Early universe as a high energy test ground

  Reconstruct the early universe (or, probe the high energy physics) which gives successful structure formation.

Prospect

- Precision cosmology:

  Determine cosmological parameters more precisely
- Origins of the parameters?

  Probe the early universe
- Non-linear processes?

  First formation of celestial objects, Dark age

Structure Formation

"Do I dare disturb the universe?"

T. S. Eliot (1888-1965)

"The universe was brought into being in a less than fully formed state, but was gifted with the capacity to transform itself from unformed matter into a truly marvelous array of structure and life forms."

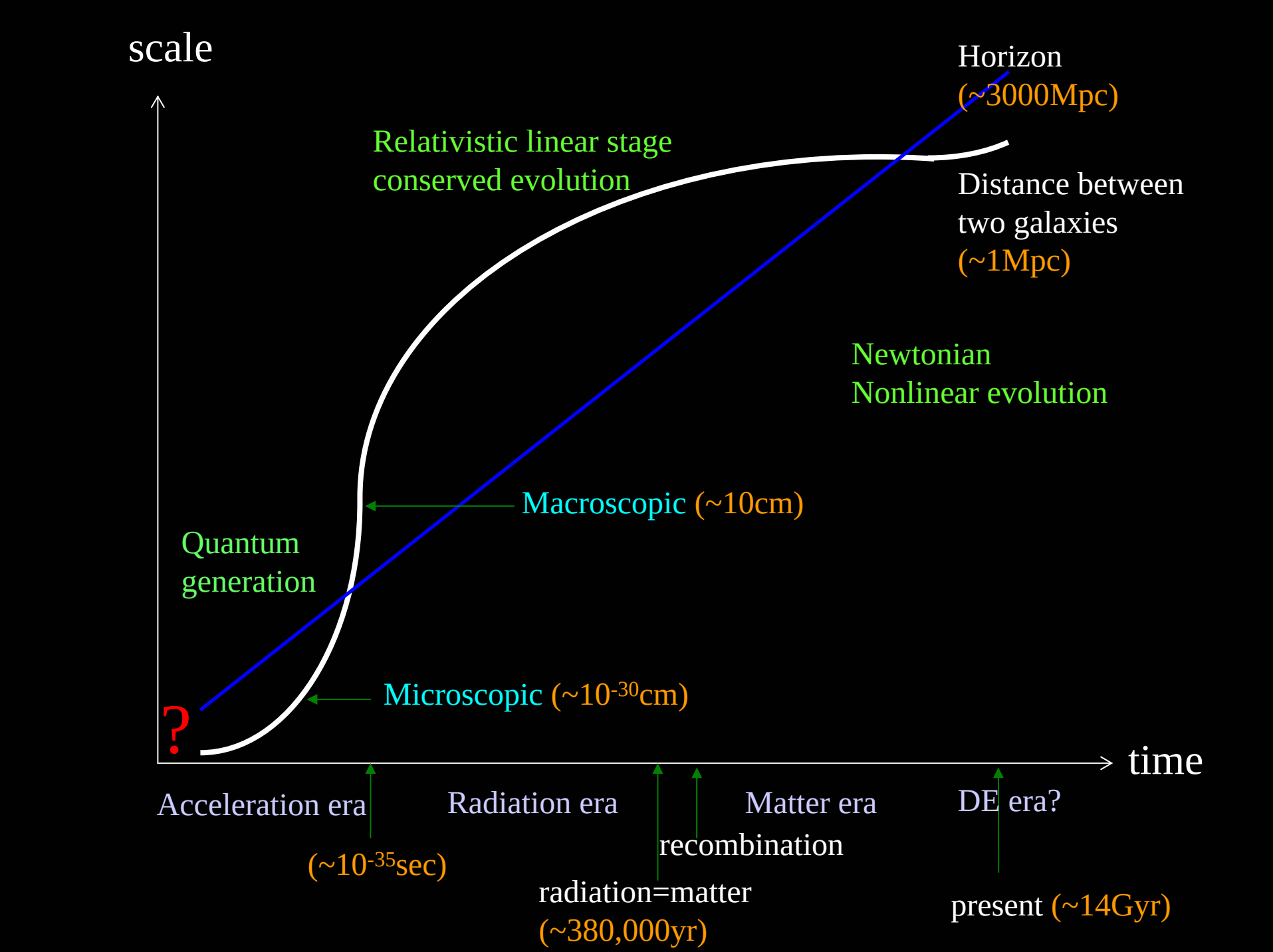
Saint Augustine (354-430)

"But if the matter was evenly disposed throughout an infinite space, it could never convene into one mass; but some of it would convene into one mass and some into another, so as to make an infinite number of great masses, scattered at great distances from one to another throughout all that infinite space."

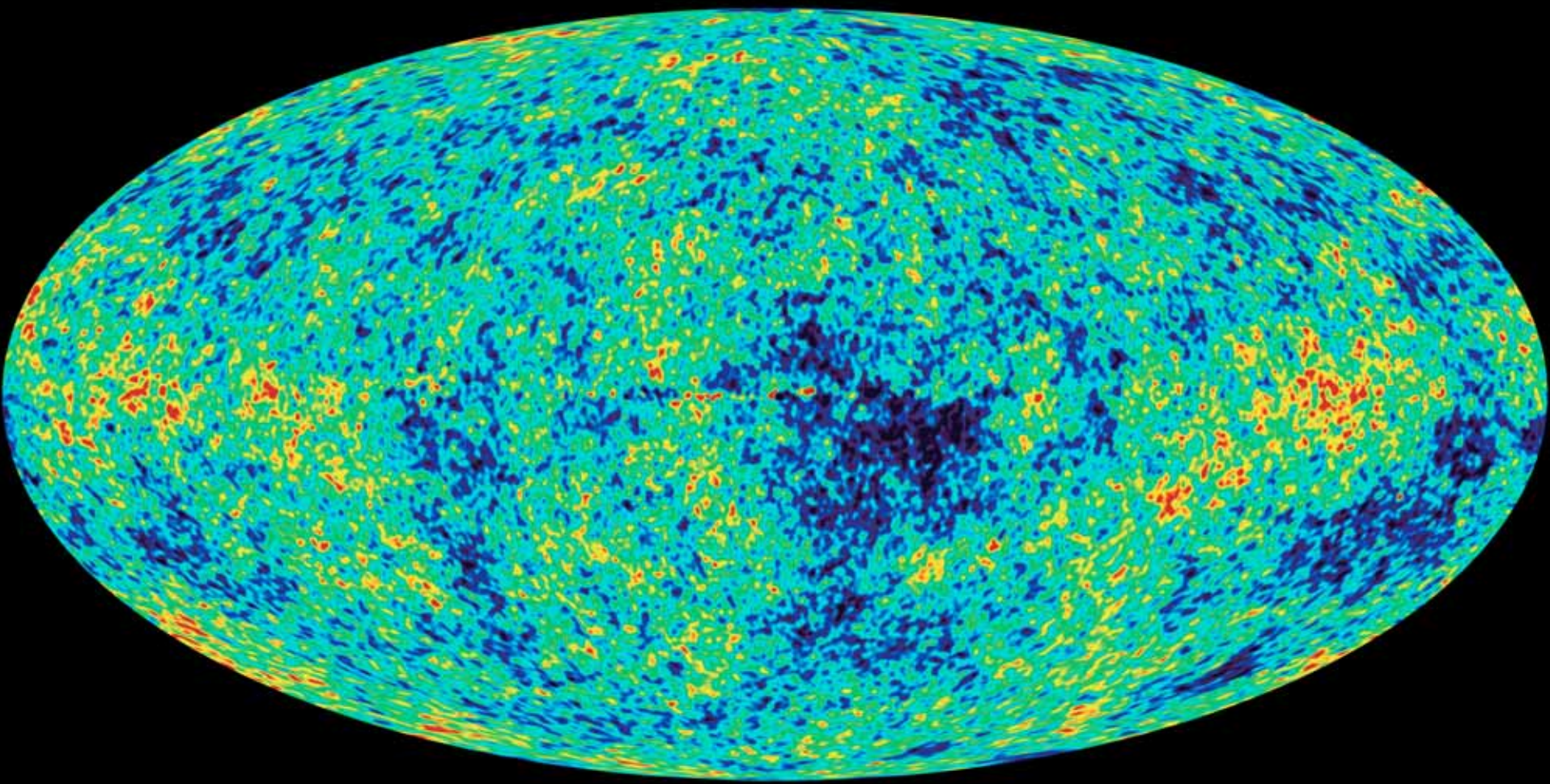
Sir Isaac Newton (1692)

Origin and evolution of LSS

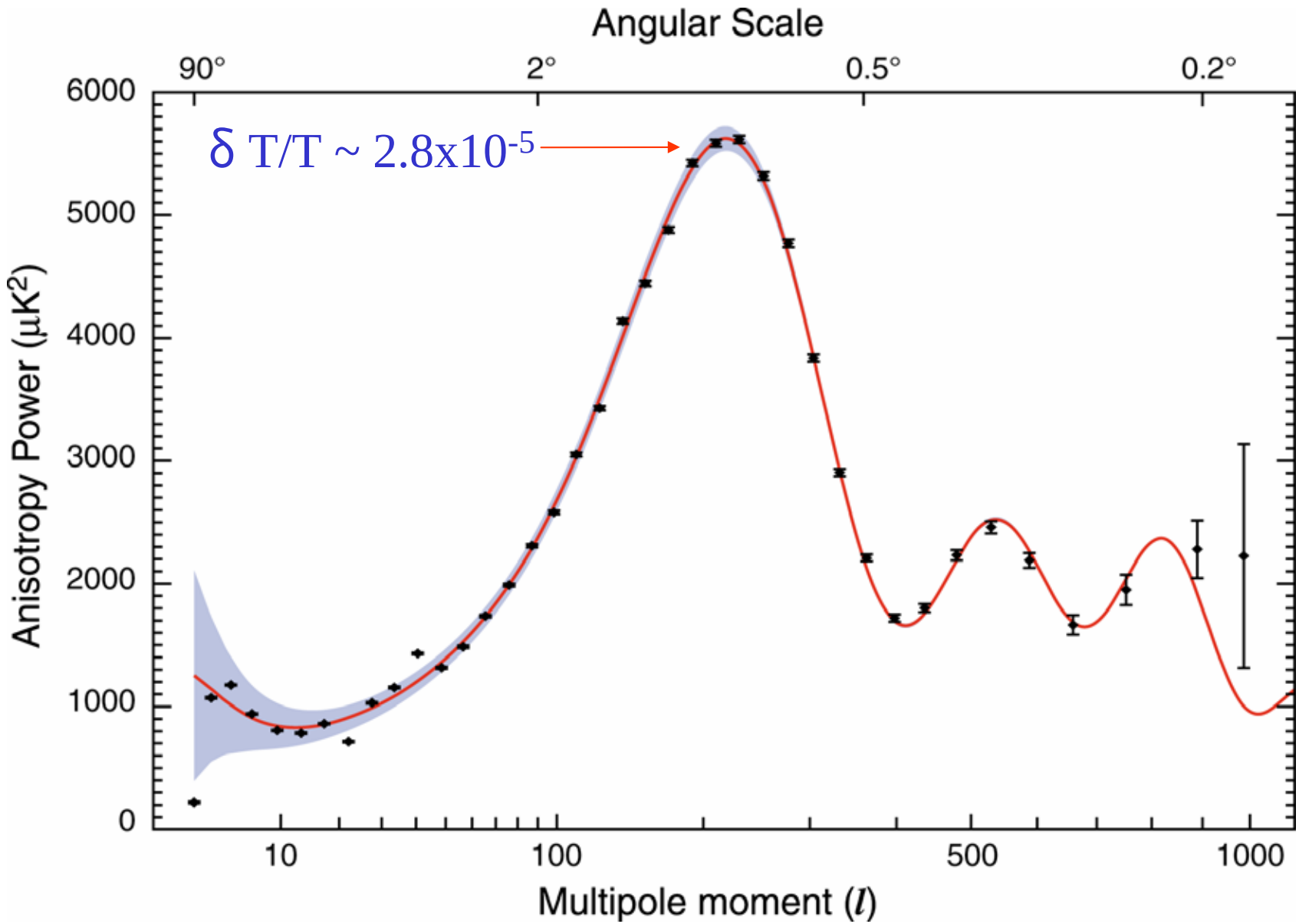
- Quantum origin
  - Space-time quantum fluctuations from uncertainty pr.
  - Become macroscopic due to inflation.
- Linear evolution (Relativistic)
  - Linear evolution of the macroscopic seeds.
  - Structures are described by conserved amplitudes.
- Nonlinear evolution (Newtonian)
  - Nonlinear evolution inside the horizon.
  - Newtonian numerical computer simulation.

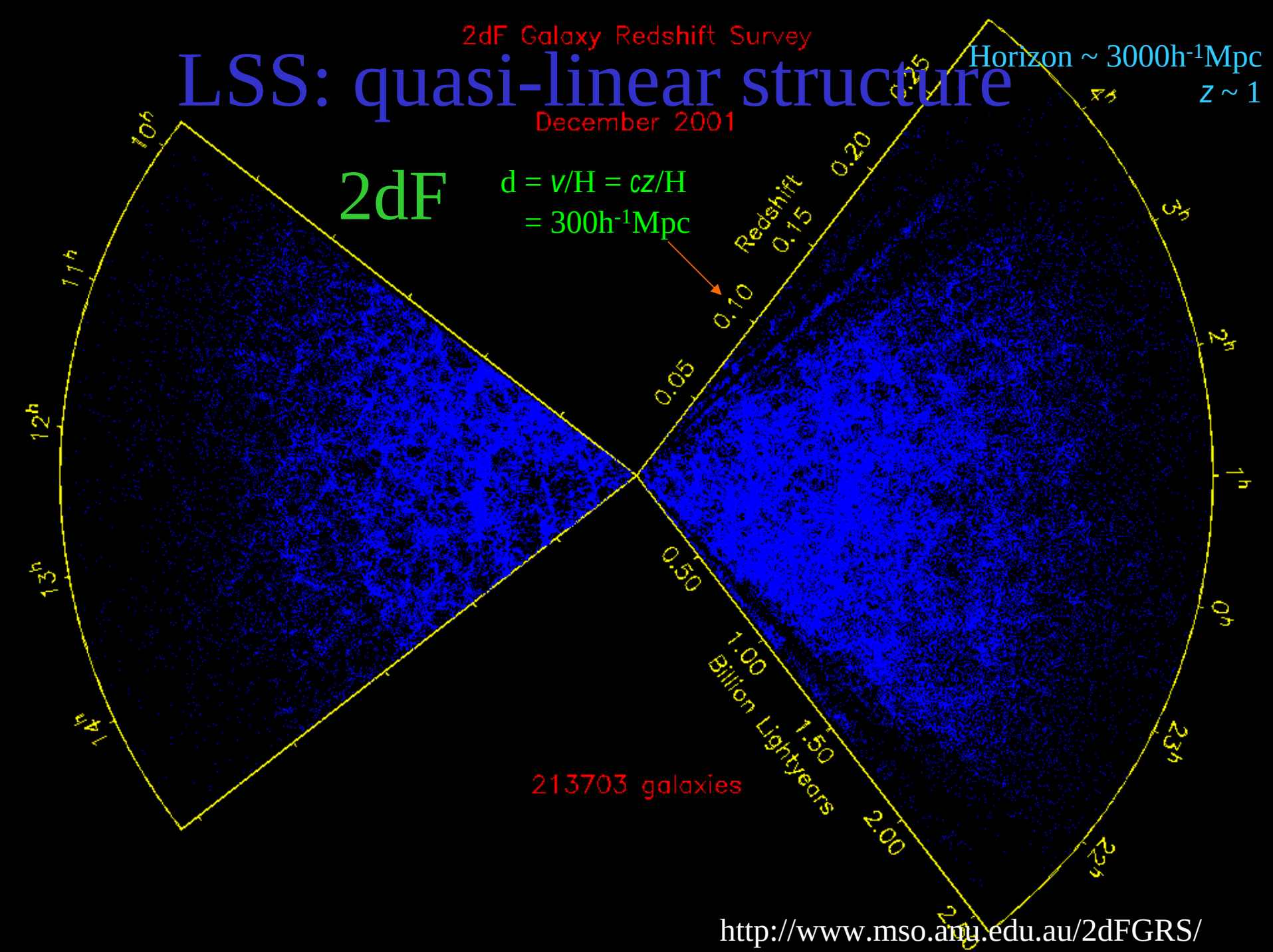

scale
Horizon
(~3000Mpc)
Relativistic linear stage
conserved evolution
Distance between
two galaxies
(~1Mpc)
Newtonian
Nonlinear evolution
Macroscopic (~10cm)
Quantum
generation
Microscopic (~10-30cm)
?
time
Acceleration era
(~10-35sec)
Radiation era
radiation=matter
(~380,000yr)
recombination
Matter era
DE era?
present (~14Gyr)

CMB: linear structure $\delta T/T \sim 10^{-5}$



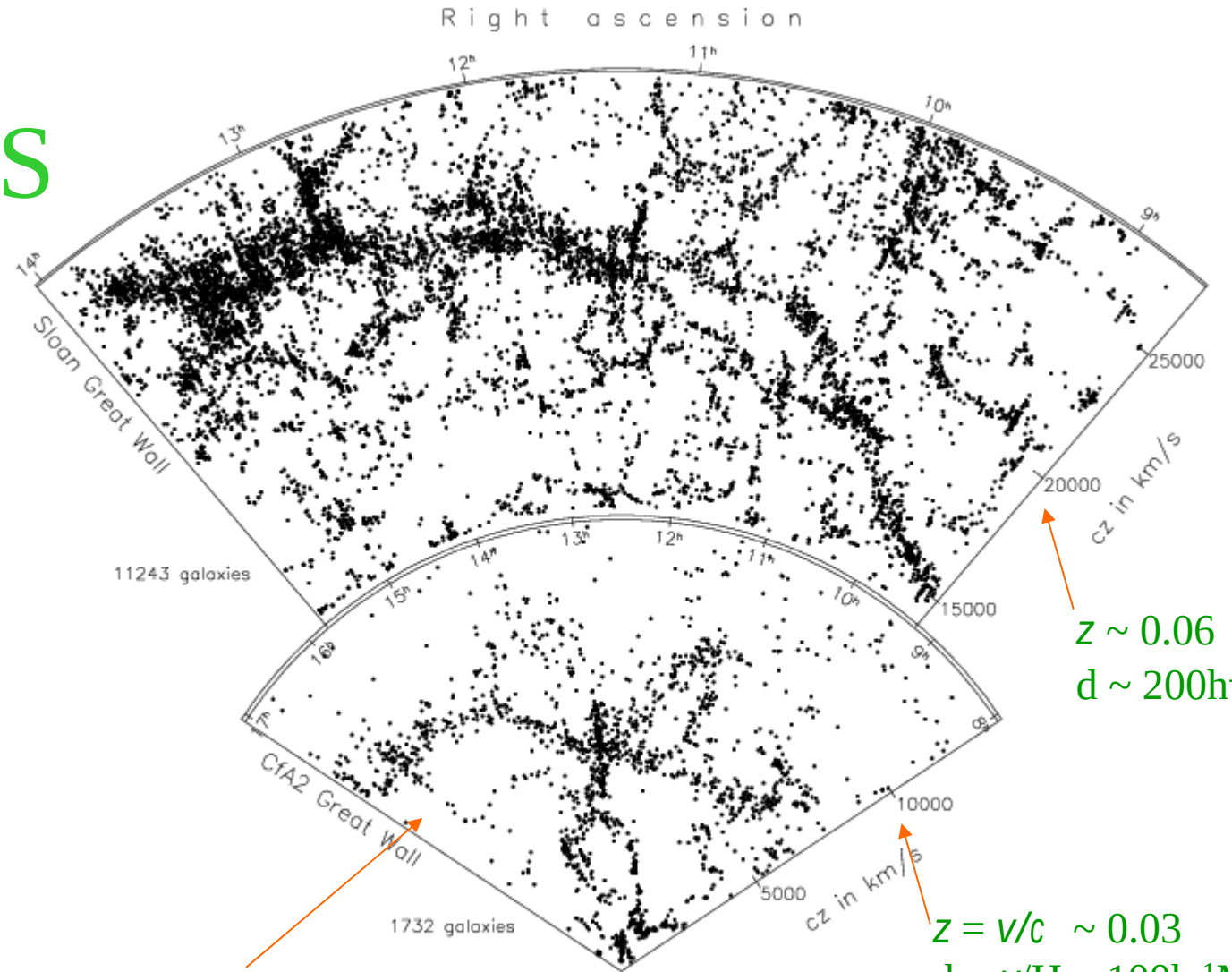
WMAP Temperature anisotropy power spectrum




2dF Galaxy Redshift Survey
LSS: quasi-linear structure
December 2001
Horizon ~ 3000h-1Mpc
z ~ 1
2dF
d = v/H = cz/H
= 300h-1Mpc
Redshift
0.05
0.10
0.15
0.20
0.25
0.30
0.50
1.00
1.50
2.00
Billion Lightyears
213703 galaxies
http://www.mso.anu.edu.au/2dFGRS/

LSS: non-linear structure

SDSS



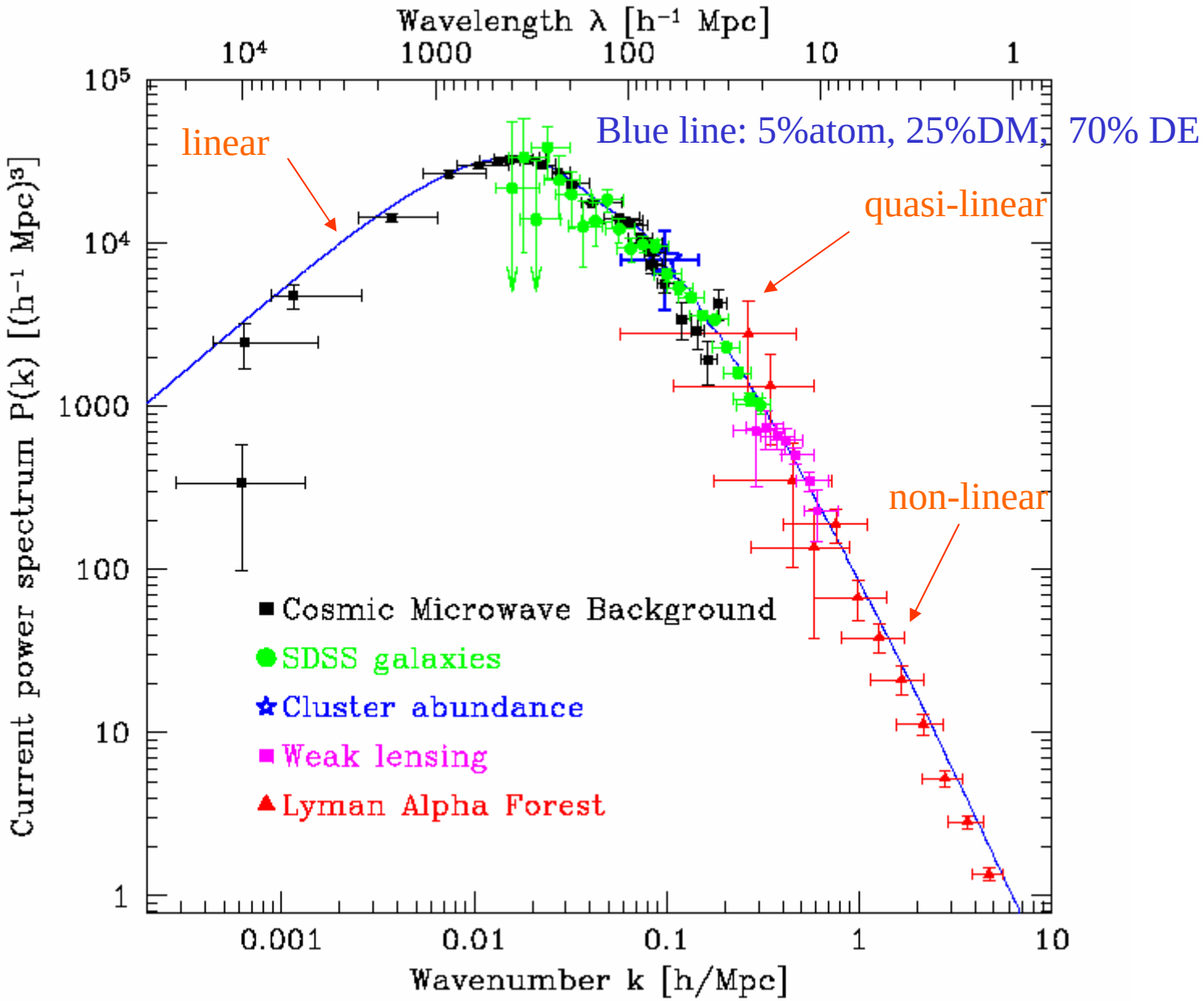
$z \sim 0.06$
$d \sim 200h^{-1}$Mpc

$z = v/c \sim 0.03$
$d = v/H \sim 100h^{-1}$Mpc

de Lapparent *etal.* (1986)

http://www.sdss.org/

Density power spectrum



Tegmark, M., et al, astro-ph/0207047 (2002)

Recent studies

- Background world model:
  - Relativistic: Friedmann (1922)
  - Newtonian: Milne (1934)
  - Coincide with zero-pressure
- Linear structures:
  - Relativistic: Lifshitz (1946)
  - Newtonian: Bonnor (1957)
  - Coincide with zero-pressure
- Second-order structures: Peebles (1980), Noh-H (2004)[a]
  - Coincide with zero-pressure, no-rotation
- Third-order structures: H-Noh (2005)[b]
  - Pure general relativistic corrections
  - δ T/T ~ 10^{-5} order higher, independent of horizon

Newtonian Relativistic

[a]Physical Review D, **69**, 104011 (2004); **72**, 044011, [b]044012 (2005)