NCPP “Trends in Particle Physics”

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COSMOLOGY

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Cosmic Microwave Background

Observational Milestones of Hot Big Bang Cosmology

- Homogeneity and isotropy and structures in the Universe
- The expansion of the Universe
- The abundance of the light elements
- The cosmic microwave background radiation

The cosmic microwave background radiation is the remnant heat left over from the Big Bang. It is an evidence for a hot early Universe.

Points to a flat LambdaCDM dominated Universe now.

$$H_0, q_0, \Omega_i (\Omega_0, \Omega_\Lambda, \Omega_M, \Omega_B, \Omega_\gamma, \Omega_\nu, \ldots), t_0, T_0, P(k), C_l$$

CMB Formation

The Big Bang theory predicts hot and dense early Universe and cooling as it expands. Thus it is filled with radiation that is the remnant heat left over from the Big Bang, called the “cosmic microwave background radiation”, or CMB.

CMB first predicted by G. Gamow and collaborators R. Alfer and R. Herman in 1948.

T>3000 K : thermodynamical equilibrium

Photons interact with electrons.

The cosmic microwave background photons easily scatter off electrons (Thompson scattering) . This process of multiple scattering and the electromagnetic interactions produced a blackbody spectrum of photons.

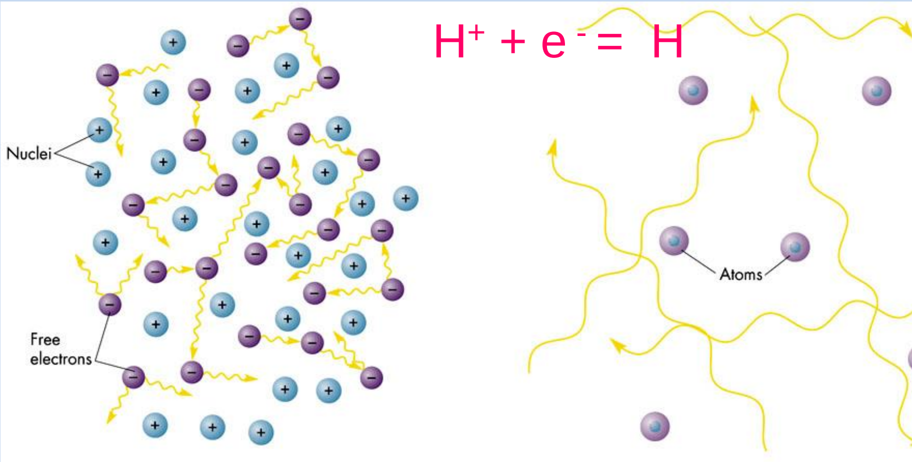
T=3000 K : Recombination 380,000 y, z=1100

The expanding Universe cooles T~1/R(t) and nuclei capture electrons to form neutral atoms.

The radiation stops to intarct.

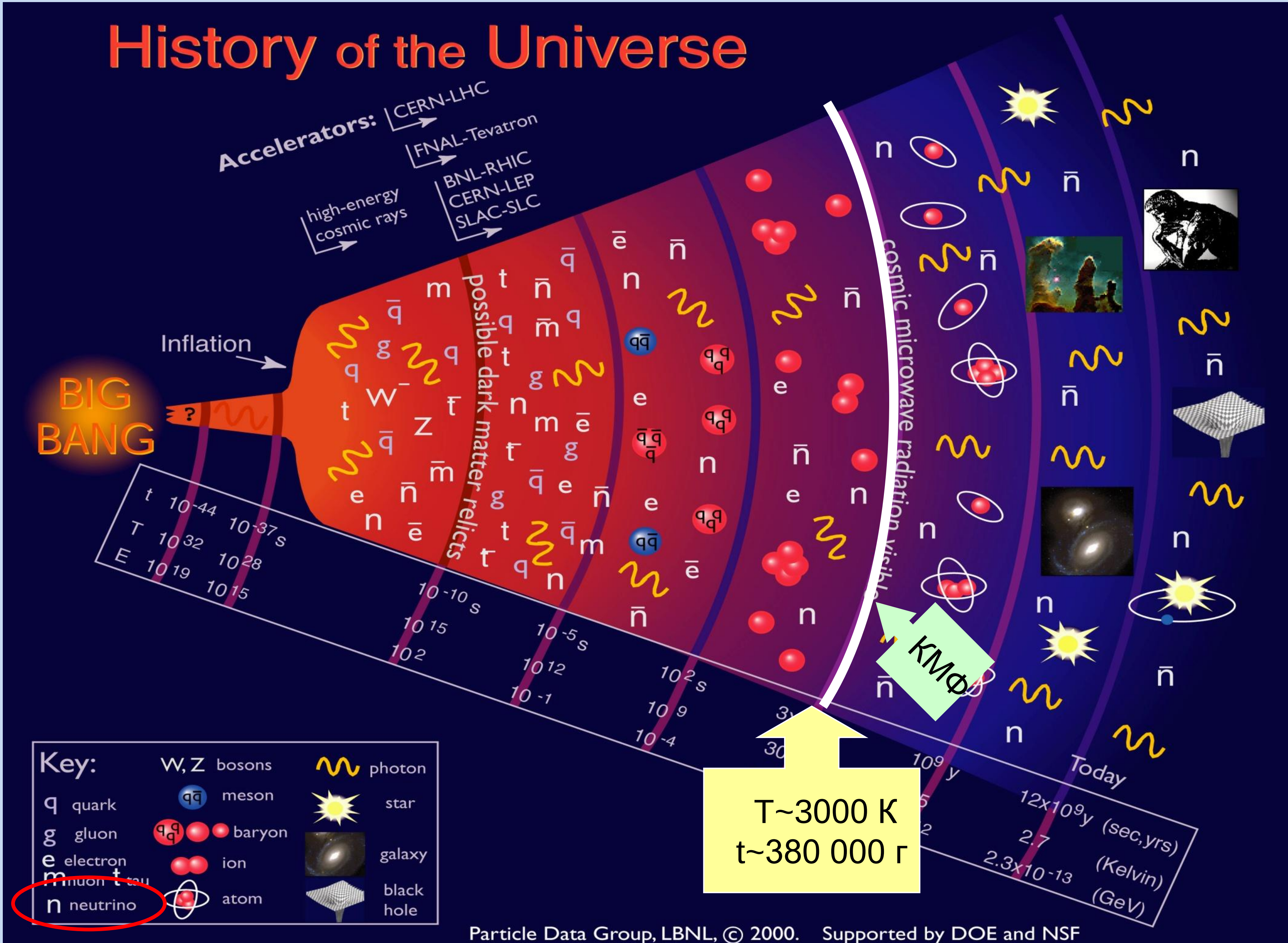
The energy of photons had decreased and was insufficient to ionise H atoms, photons “decoupled” from the other particles and could move through the Universe essentially unimpeded. Universe becomes **transparent** to radiation.

CMB emitted detectable by radio telscopes.



The cooling blackbody radiation in an expanding Universe retains its blackbody form (Tolman 1934) .

It was detected by radio telescopes. We observe it as a 2.7 K thermal blackbody radiation filling the entire Universe.



History of the Universe
Accelerators:
CERN-LHC
FNAL-Tevatron
BNL-RHIC
CERN-LEP
SLAC-SLC
high-energy cosmic rays
Inflation
BIG BANG
possible dark matter relicts
cosmic microwave radiation visible
t 10-44 10-37 s
T 10 32 10 28
E 10 19 10 15
10 -10 s
10 15
10 2
10 -5 s
10 12
10 -1
10 2 s
10 9
10 -4
10⁹ y
Today
12x10⁹y (sec,yrs)
2.7 (Kelvin)
2.3x10 -13 (GeV)
КМФ
T~3000 K
t~380 000 г
Key:
q quark
g gluon
e electron
m muon t tau
n neutrino
W, Z bosons
meson
baryon
ion
atom
photon
star
galaxy
black hole
Particle Data Group, LBNL, © 2000. Supported by DOE and NSF

The Cosmic Background Radiation
History

The Big Bang theory predicts hot and dense early Universe and cooling as it expands. Thus it is filled with radiation that is the remnant heat left over from the Big Bang, called the “cosmic microwave background radiation”, or CMB.

Some measurements as early as 1940 had found that a radiation field was necessary to explain energy level transitions in interstellar molecules (McKellar 1941)

- G. Gamov (1946) predicted CMB and calculated its temperature, more precise calculations provided by Ralph Alpher and Robert Herman in 1950

- In 1964, Doroshkevich and Novikov explicitly suggested a search for the radiation focusing on its blackbody characteristics.

- R. Dicke, P. Peebles, P. Roll, D. Wilkinson, (1964) Princeton University: were devising an experiment to find the CMB.

.

- Following 1964 discovery, independent measurements were made by Wilkinson and others, using balloon-borne, rocket-borne or ground based instruments.

The intensity of the radiation has its maximum for a wavelength of about 1 mm where the absorption in the atmosphere is strong.

Although most results gave support to the blackbody form, few measurements were available on the high frequency. Measurements of the high frequency part of the CMB spectrum (wavelengths shorter than about 1 mm) possible from space.

- 1992, the Cosmic Background Explorer (**COBE**) satellite detected cosmological fluctuations in the microwave background temperature

(see however pioneer Relikt results)

- WMAP – precision cosmology

CMB discovery

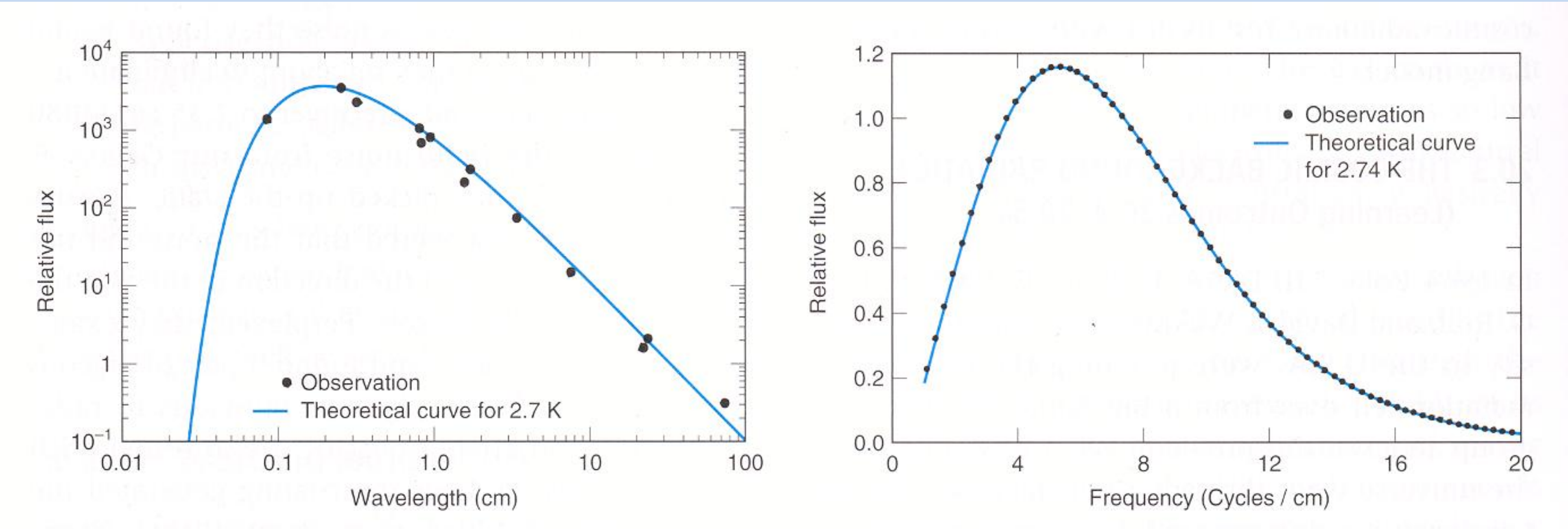
- **A. Penzias, R. Wilson, (1964) Bell Labs, Murray Hill, NJ – first observed CBR (the radiation was acting as a source of excess noise in a radio receiver they were building).**

Penzias and Wilson shared the 1978 Nobel prize in physics for their discovery.

Measured Plank's curve

By A. Penzias, R. Wilson (left); by COBE (right)

The FIRAS experiment measured the spectrum at 34 equally spaced points along the blackbody curve. The error bars are so small that they can not be seen under the predicted curve in the figure!



CMB Detection and Characteristics

1964 A. Penzias & R.Wilson

detect noise in the radio antena, not dependent on the direction.

2.7 K blackbody

Isotropic (<1%)

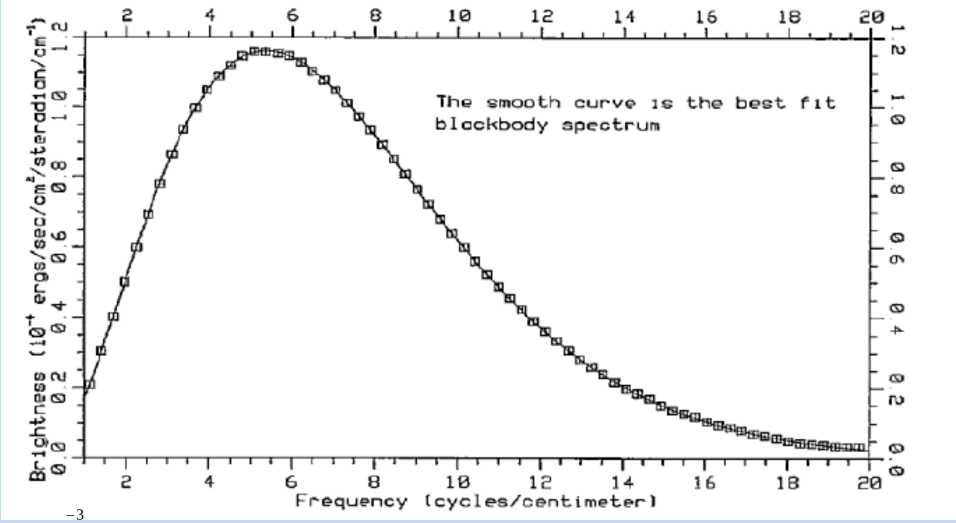
Relic of the early 380 000 y

hot 3 000 K Universe

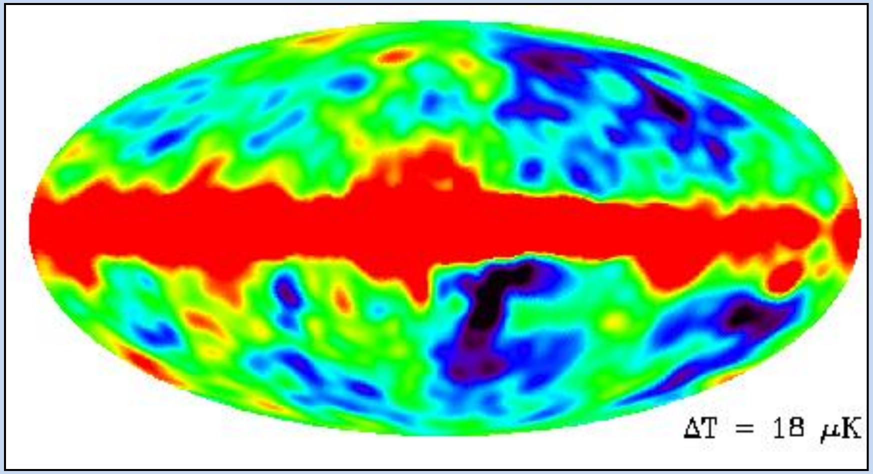
1970's and 1980's

3 mK dipole (local Doppler) due to the Earth movements towards Hydra Centaurus superclusters v=600 km/s.

$\delta T/T < 10^{-5}$



Maximum at 1 mm where the absorption of the atmosphere is big, hence studied by cosmic missions



RELIKT (1983-84)

COBE (1989-93)

1992: $\delta T/T \approx 5.10^{-6}$

T= 2.728 K

T= 2.725 0.001 K 411cm^{-3}

T fluctuations 13 4 μK $\ell < 30 : \delta T/T \approx 10^{-5}$

2006 Nobel Prize in Physics (G. Smoot, J.Mather)

"for their discovery of the blackbody form and anisotropy of the Cosmic microwave background radiation"

Precise measurements of Universe characteristics: density, age, geometry, reionization , ...

Relikt 1

http://lambda.gsfc.nasa.gov/product/relikt/

The Relikt Experiment Prognoz 9, launched on 1 July 1983 investigated the anisotropy of the CMB at 37 GHz, using a Dicke-type modulation radiometer. During 1983 and 1984 some 15 million individual measurements were made (with 10% near the galactic plane providing some 5000 measurements per point). The entire sky was observed in 6 months. The angular resolution was 5.5 degrees, with a temperature resolution of 0.6 mK. The galactic microwave flux was measured and the CMB dipole observed. A quadrupole moment was found between 17 and 95 microKelvin rms, with 90% confidence level. A map of most of the sky at 37 GHz is available.

- *References: I.A. Strukov, A.A. Brukhanov, D.P. Skulachev and M.V. Sazhin. Pis'ma v Astronomicheskii Zhurnal v.18 (1992), 387 (in Russian, English version: Soviet Astronomy10 Letters 18 (1992), 153). I.A. Strukov, A.A. Brukhanov, D.P. Skulachev and M.V. Sazhin. Mon. Not. R. Astron. Soc. 258 (1992), 37p.* Letters 18 (1992), 153).

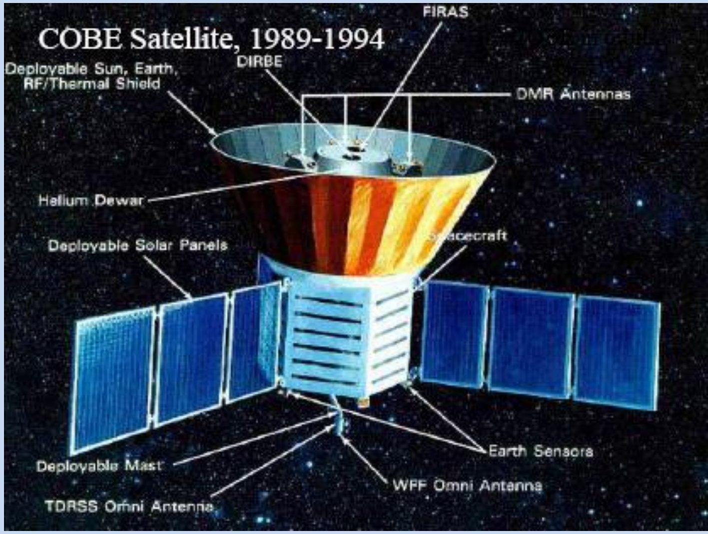
I.A. Strukov, A.A. Brukhanov, D.P. Skulachev and M.V. Sazhin. Mon. Not. R. Astron. Soc. 258 (1992), 37p.11

COBE

COsmic Background Explorer 1989-94

COBE was launched November 18, 1989 and carried three instruments covering the wavelength range 1 µm to 1 cm to measure the anisotropy and spectrum of the CMB as well as the diffuse infrared background radiation

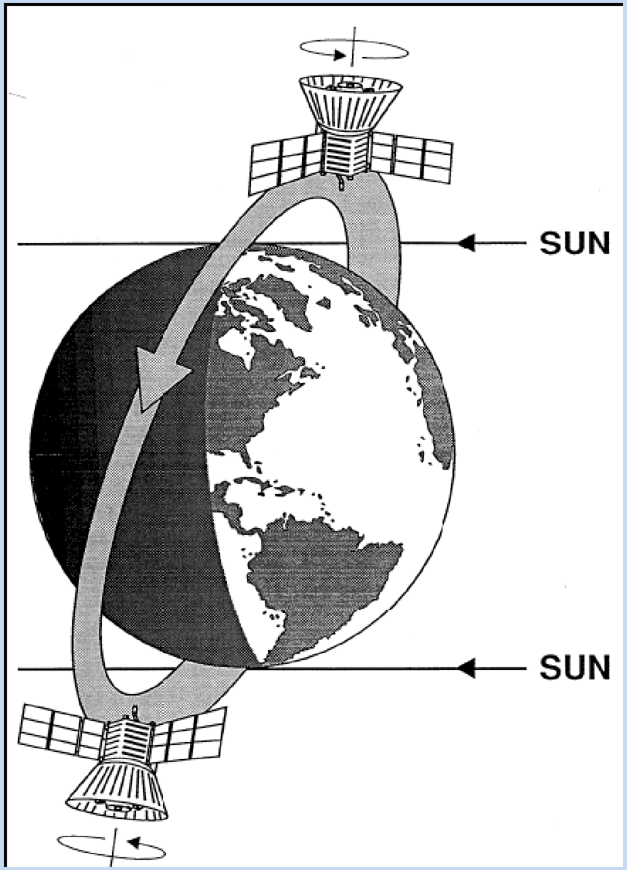
John Mather was the COBE Principal Investigator and the project leader from the start.



Diffuse Infrared Background Experiment to search for the cosmic infrared background radiation, Mike Hauser

Differential Microwave Radiometers (DMR) to map the cosmic radiation sensitively principal investigator George Smoot
The objective was to search for anisotropies at three wavelengths, 3 mm, 6 mm, and 10 mm in the CMB with an angular resolution of about 7°.

Far Infrared Absolute Spectrophotometer (FIRAS) to measure the spectral distribution of the CMB in the range 0.1 – 10 mm and compare it with the blackbody form expected in the Big Bang , John Mather

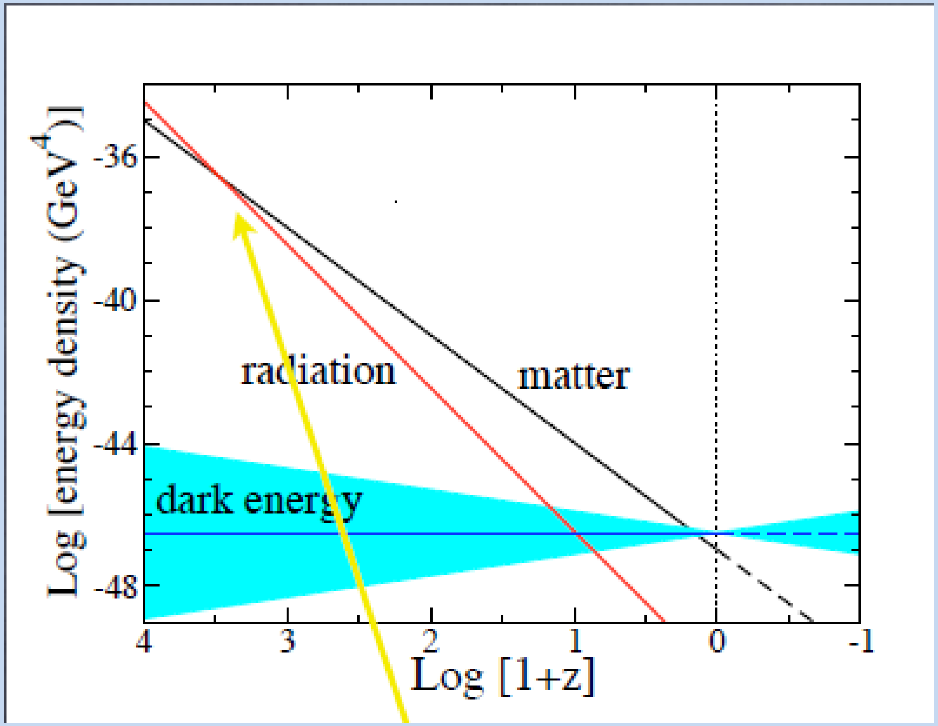


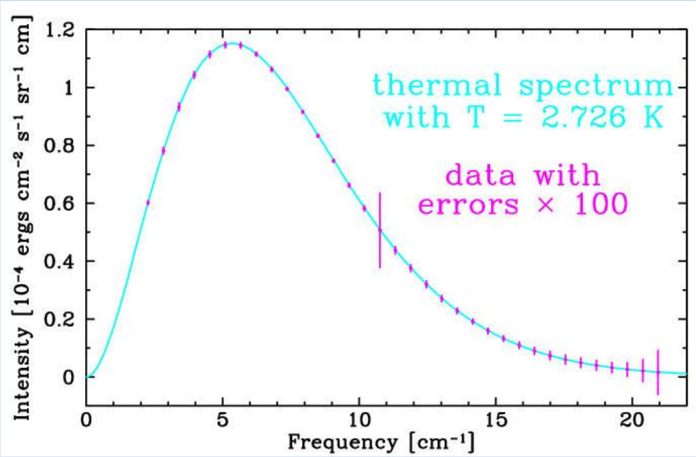
- **The COBE orbit and spin axis orientation chosen to measure the CMB over the entire sky. All previous measurements from ground were done with limited sky coverage.**

The spin axis pointed almost perpendicular to the direction of the Sun and in an outward direction from the Earth. As the COBE orbited the Earth once every 103 minutes, it viewed a circle on the sky 94 degrees away from the Sun, and as the Earth moves around the Sun over the course of a year the COBE gradually scaned the entire sky.

Schematic view of COBE in orbit around the earth. The altitude at insertion was 900 km.

CMB is a direct evidence for an early hot stage of the Universe:





$$\rho_M \sim R^{-3}$$

$$\rho_M \sim \rho_R$$

$$\rho_R \sim R^{-4}$$

The results from COBE

Temperature fluctuations of the order of 10^{-5} were found and the background radiation with a temperature of 2.725 K followed very precisely a blackbody spectrum.

- The spectrum of the radiation (measured in the wavelength range 0.1 – 10 mm) is extremely uniform, with less than 1 % deviation from that of a blackbody..
- Final result for the temperature 2.725 0.002 K Largest deviations were 0.03%

WMAP obtained better accuracy: T= 2.725 0.001 K

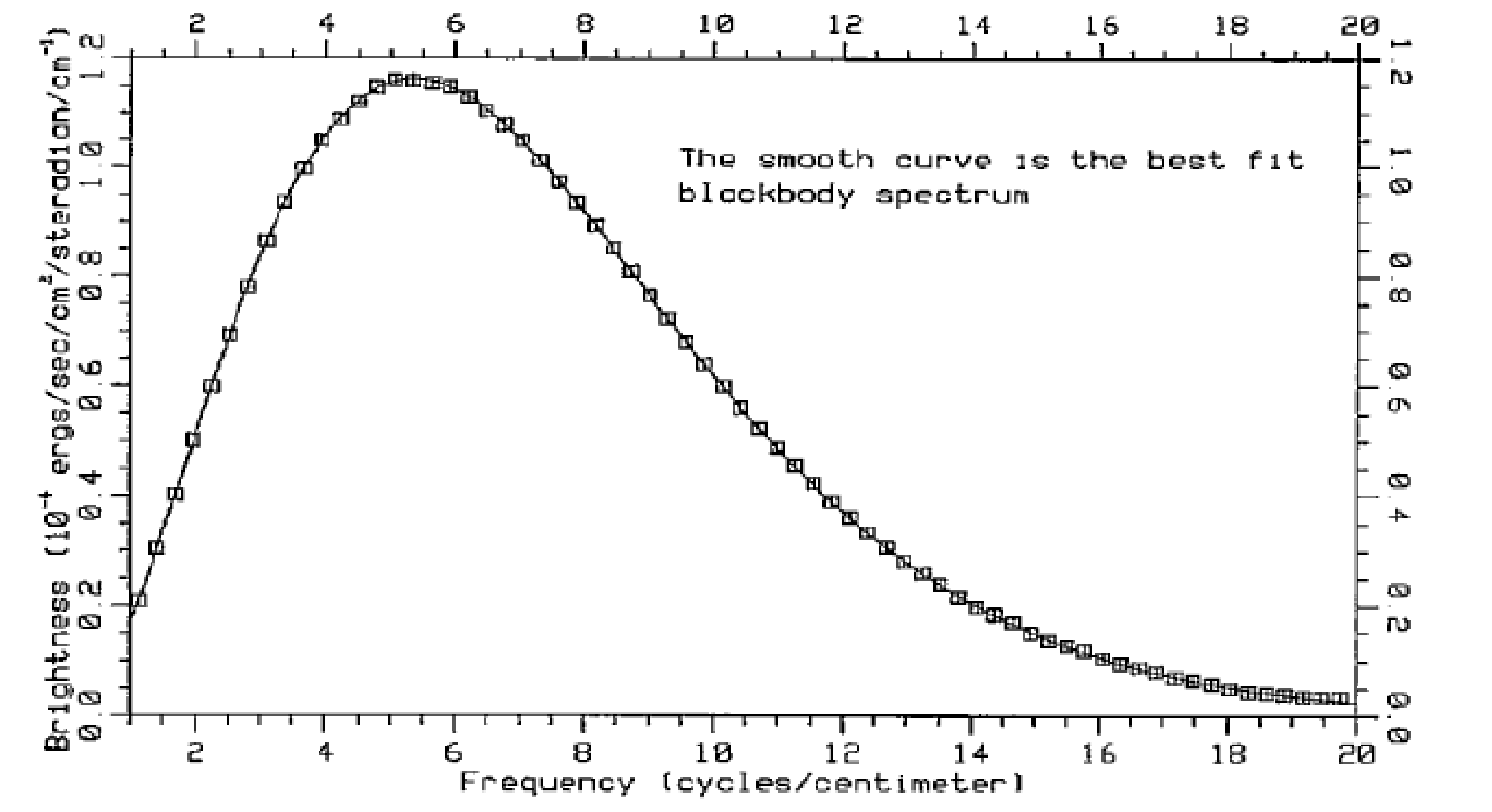
corresponing to particle density of 411 per cubic cm

and energy density 4.64 10E-34 g/cm

There is no alternative theory yet proposed that predicts this energy spectrum. The accurate measurement of its shape was another important test of the Big Bang

CMB is probably the best recorded blackbody spectrum that exists.

The first FIRAS result (Mather et al. 1990). Data had been accumulated during nine minutes in the direction of the northern galactic pole. The small squares show measurements with an error estimate of 1%. T=2.735 ± 0.060 .



Properties of the CBR

- Isotropic, except for the motion of the earth (together with the local cluster) towards Hydra and Centaurus super-cluster with velocity of v=600 km/s.

  dipole temperature anisotropy $dT/T = 10^{-3}$

(*Conklin 1969, Henry 1971, Corey and Wilkinson 1976 and Smoot, Gorenstein and Muller 1977*)

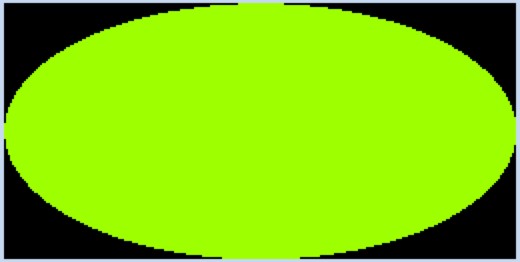
- Anisotropy

To explain the large scale structures in the form of galaxies and clusters of galaxies observed today, small anisotropies should exist.
Gravitation can make small density fluctuations that are present in the early Universe grow and make galaxy formation possible.
During 1970-ties the anisotropies expected $10^{-2} – 10^{-4}$, but not observed experimentally.
Dark matter taken into account in the 1980-ties, the predicted level of the fluctuations was lowered to about 10^{-5}, thereby posing a great experimental challenge.

$$\frac{\delta T}{T} \sim \frac{\delta \rho}{\rho}$$

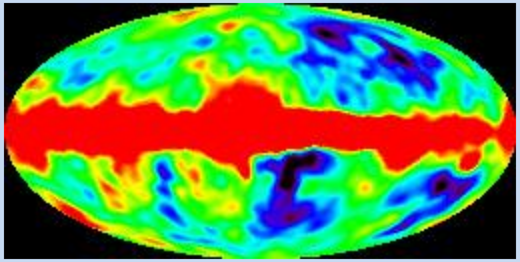
Anisotropy of CMB

In 1992, CMB Explorer satellite made the first detection of anisotropies fluctuations in CMB temperature for three frequencies, 90, 53 and 31.5 GHz (wavelengths 3.3, 5.7 and 9.5 mm), chosen near the CMB intensity maximum and where the galactic background was low (first indications by Relikt - 1990)



The hot regions, are 4 Kelvin

hotter than the blue ones.

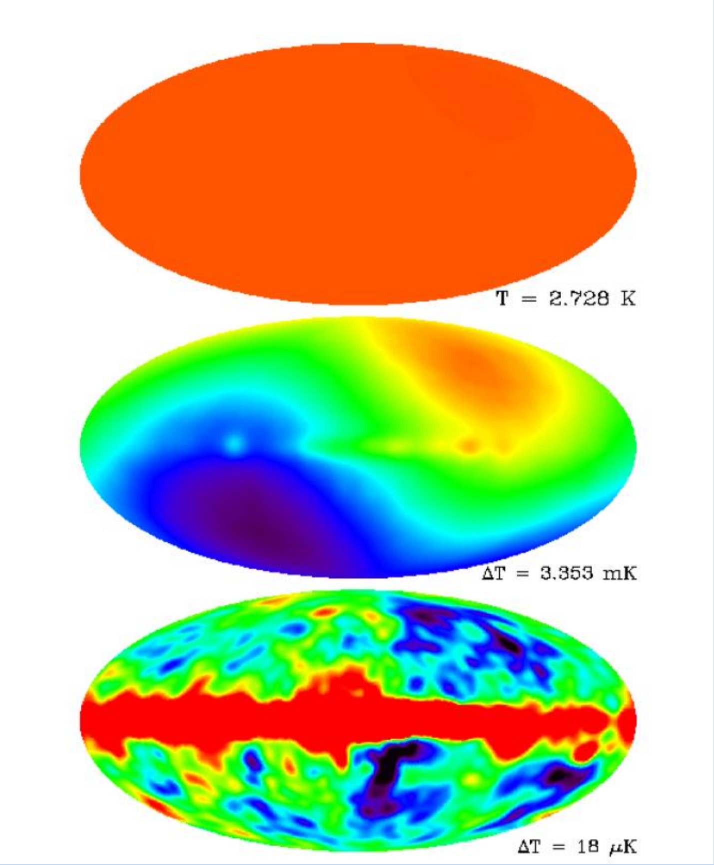


The hot regions, shown in red, are 0.0002 Kelvin hotter than the blue ones.

The bottom image shows the sky as seen at microwave frequencies, after the dipole anisotropy due to the Sun motion relative to the rest frame of the CMB has been subtracted from the map.

Main sources for the fluctuations:
The emission of the Milky Way dominates the equator of the map.
Fluctuating emission from the edge of the visible universe dominates the regions away from the equator.
There is also residual noise from the instruments themselves, but it is small compared to the signals in these maps.

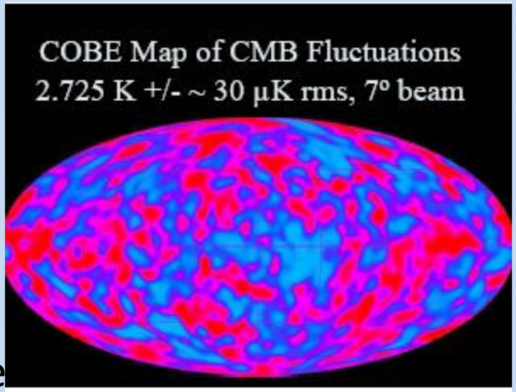
DMR results



DMR results (Smoot et al. 1992, http://lambda.gsfc.nasa.gov/product/cobe/) in galactic coordinates

The data from the 53 GHz band (6 mm wavelength) showing the near uniformity of the CMB (top), the dipole (middle) and the quadrupole and higher anisotropies with the dipole subtracted (bottom). The relative sensitivities from top to bottom are 1, 100 and 100,000. The background from the Milky Way, not following a blackbody spectrum (visible as a horizontal red band in the bottom panel), has not been subtracted.

- The RMS cosmic quadrupole amplitude was estimated at 13 ± 4 μK ($\Delta T/T = 5\times10^{-6}$) with a systematic error of at most 3 μK.
- The DMR anisotropies were compared and found to agree with models of structure formation by Wright et al. 1992.



- Most models for structure formation predict that temperature variations have Gaussian distribution for large angles (corresponding to the DMR measurements). In inflation models the Gaussian distribution originates from primordial quantum fluctuations. COBE's DMR data showed Gaussian, near scale-invariant temperature fluctuations and in that sense provides support for inflation models (Kogut et al. 1996).

COBE's results were soon confirmed by a number of balloon-borne experiments, and, more recently, by the 1° resolution WMAP (Wilkinson Microwave Anisotropy Probe) satellite, launched in 2001 (Bennett et al. 2003).

- *Mather and Smoot shared the 2006 Nobel prize in physics for their discovery.*

2006 Nobel Prize in Physics

- Info http://www.kva.se

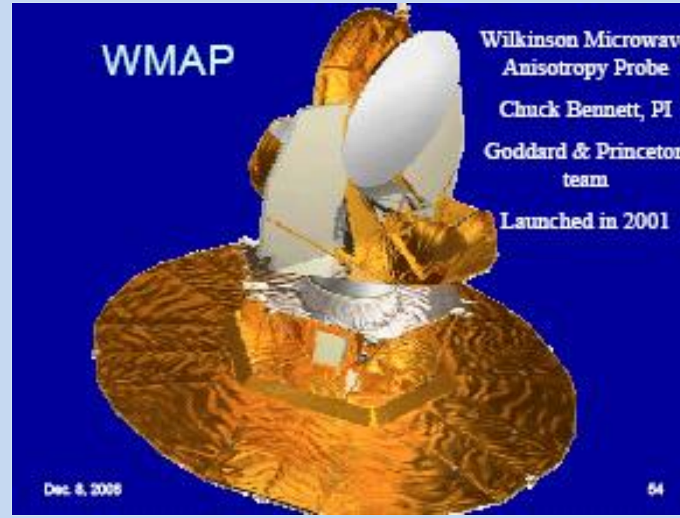
Press Release 3 October 2006
The Nobel Prize in Physics 2006 The Royal Swedish Academy of Sciences has decided to award the Nobel Prize in Physics for 2006 jointly to John C. Mather (NASA Goddard Space Flight Center, Greenbelt, MD, USA), and George F. Smoot (University of California, Berkeley, CA, USA) ”for their discovery of the blackbody form and anisotropy of the Cosmic microwave background radiation” .
They have made measurements looking back into the infancy of the Universe and attempted to gain some understanding of the origin of galaxies and stars.

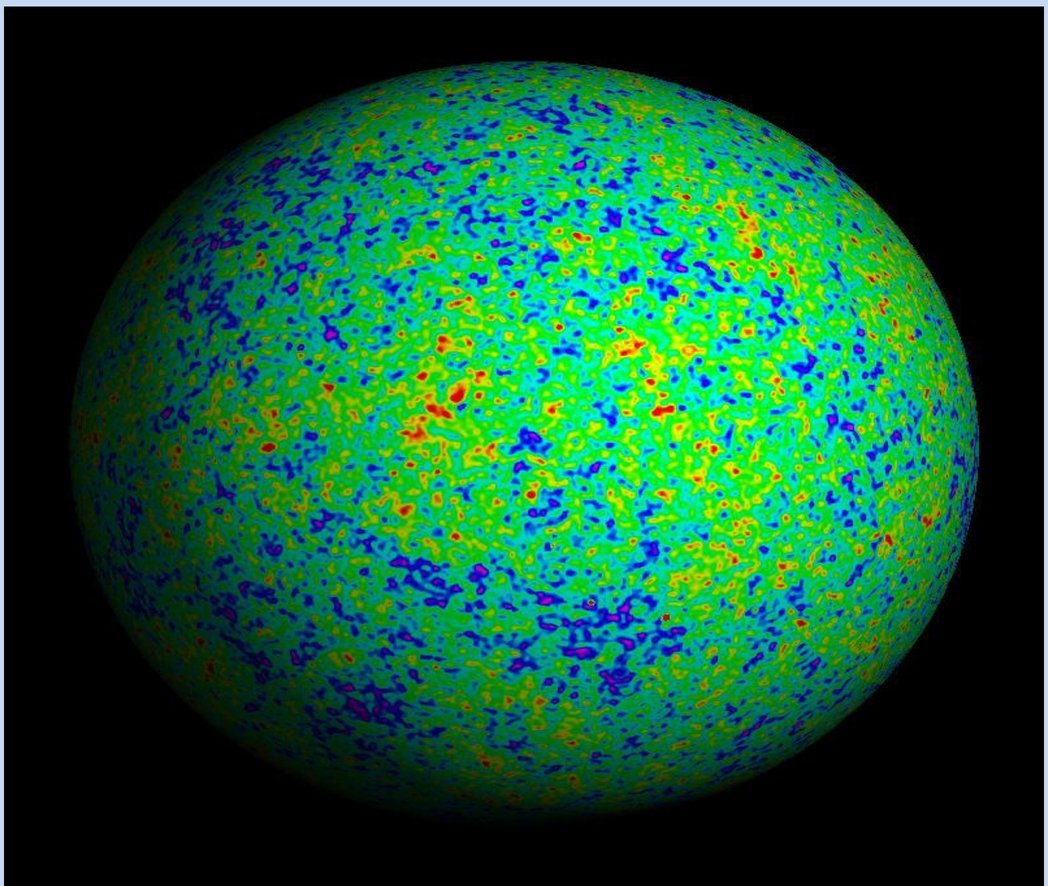
Some CMB results

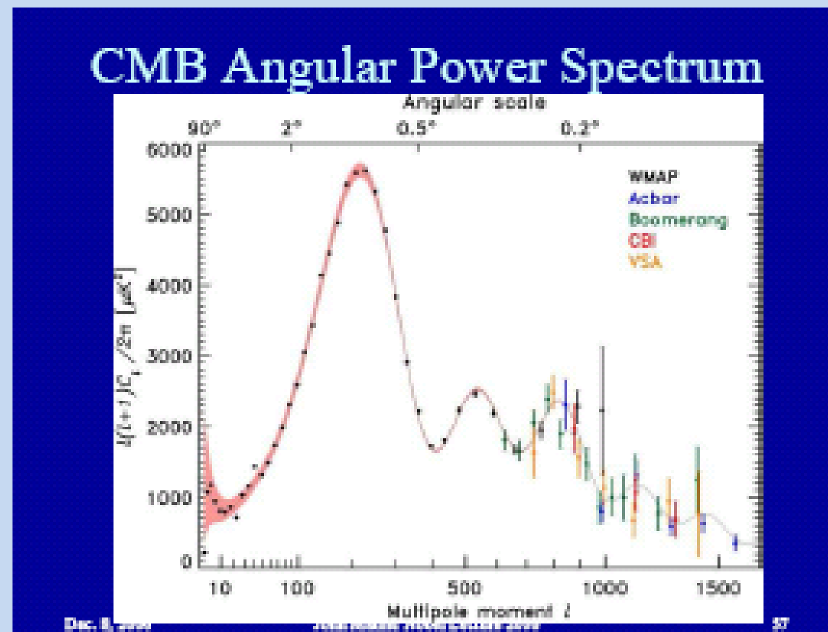
- Strong support to the Big Bang model in proving the cosmological origin of the CMB and finding the primordial seeds of the large structures observed today.
- Estimâtes the ammount of total matter (support of inflationary hypothesis)
- estimate the amount of dark matter in the Universe (link with particle physics, and in particular the Large Hadron Collider accelerator at CERN which may soon show evidence for new particles,such as susy particles that can account for the DM)
- Estimate the ammount of baryon matter in accordance with BBN– the triumph of BBN paradigm!
- Universe Age from CMB: 13.7 Blny
- Give unique and detailed information about the early Universe, thereby promoting cosmology to a precision science.

WMAP

COBE’s results were soon confirmed by a number of balloon-borne experiments, and, more recently, by the 1 resolution WMAP (Wilkinson Microwave Anisotropy Probe) satellite, launched in 2001 (Bennett et al. 2003).







Main CMB Results

WMAP measures the density of baryonic and non-baryonic matter to an accuracy of better than 5%. It is able to determine some of the properties of the non-baryonic matter: the interactions of the non-baryonic matter with itself, its mass and its interactions with ordinary matter all affect the details of the cosmic microwave background fluctuation spectrum.

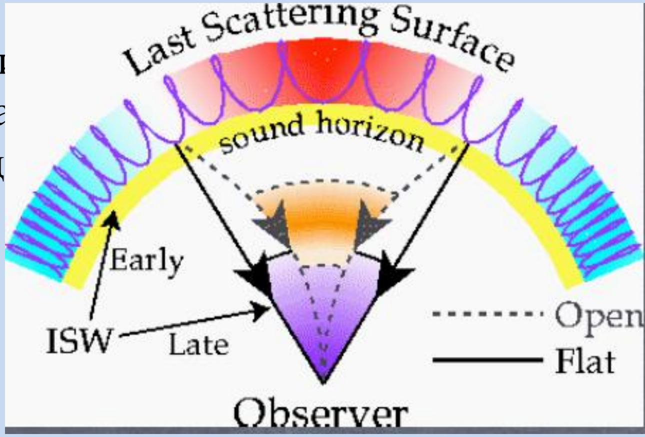
WMAP determined that the universe is flat: the mean energy density is equal to the critical density (within a 2% margin of error), equivalent to a 9.9 x 10-30 g/cm3 (5.9 protons per cubic meter).

4% Atoms, 23% Cold Dark Matter, 73% Dark Energy. Thus 96% of the energy density in the universe is in a form that has never been directly detected in the laboratory. Fast moving neutrinos do not play any major role in the evolution of structure in the universe. They would have prevented the early clumping of gas in the universe, delaying the emergence of the first stars, in conflict with the new WMAP data.

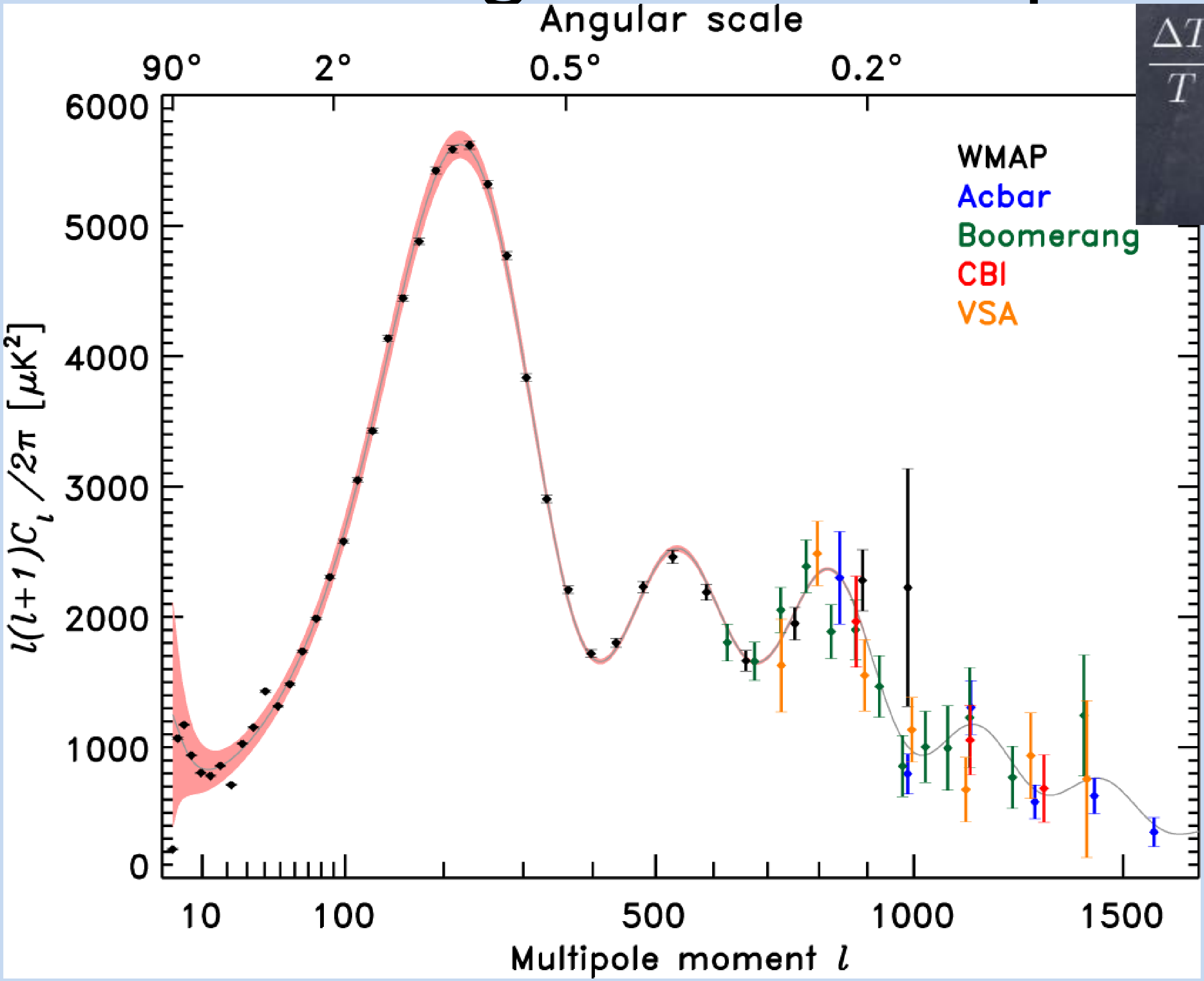
The data places new constraints on the Dark Energy. It seems more like a "cosmological constant" than a negative-pressure energy field called "quintessence". But quintessence is not ruled out.

– Sound waves: Лъчистото налягане противодейства на опитите на гравитацията да свие газа в потенциалните ями, довеждащи до акустични осцилации, които водят до пространствени вариации на КМФ температура с времето.

Фотон-барионната система флуид спира да осцилира при рекомбинацията. Осцилациите са замразени при рекомбинаци
Модите хванати в максимум на осцилациите им представлява
максимумите. Пространствените вариации на T да се наблюд
като вариации по ъгли с увеличаване на ъгловия размер.



CMB Angular Power Spectrum



$$\frac{\Delta T}{T} = \sum_{lm} a_{lm} Y_{lm}(\theta, \phi)$$

$$C_l = \langle |a_{lm}|^2 \rangle$$

Location and height of acoustic peaks determine the values of cosmological parameters.

Relevant parameters

curvature

(e.g. open, flat, closed)

dark energy

(e.g. cosmological constant)

amount of baryons

(e.g. electrons & nucleons)

amount of matter

(e.g. dark matter)

WMAP+ 3yr TT power spectrum (Hinshaw et al. 2006)

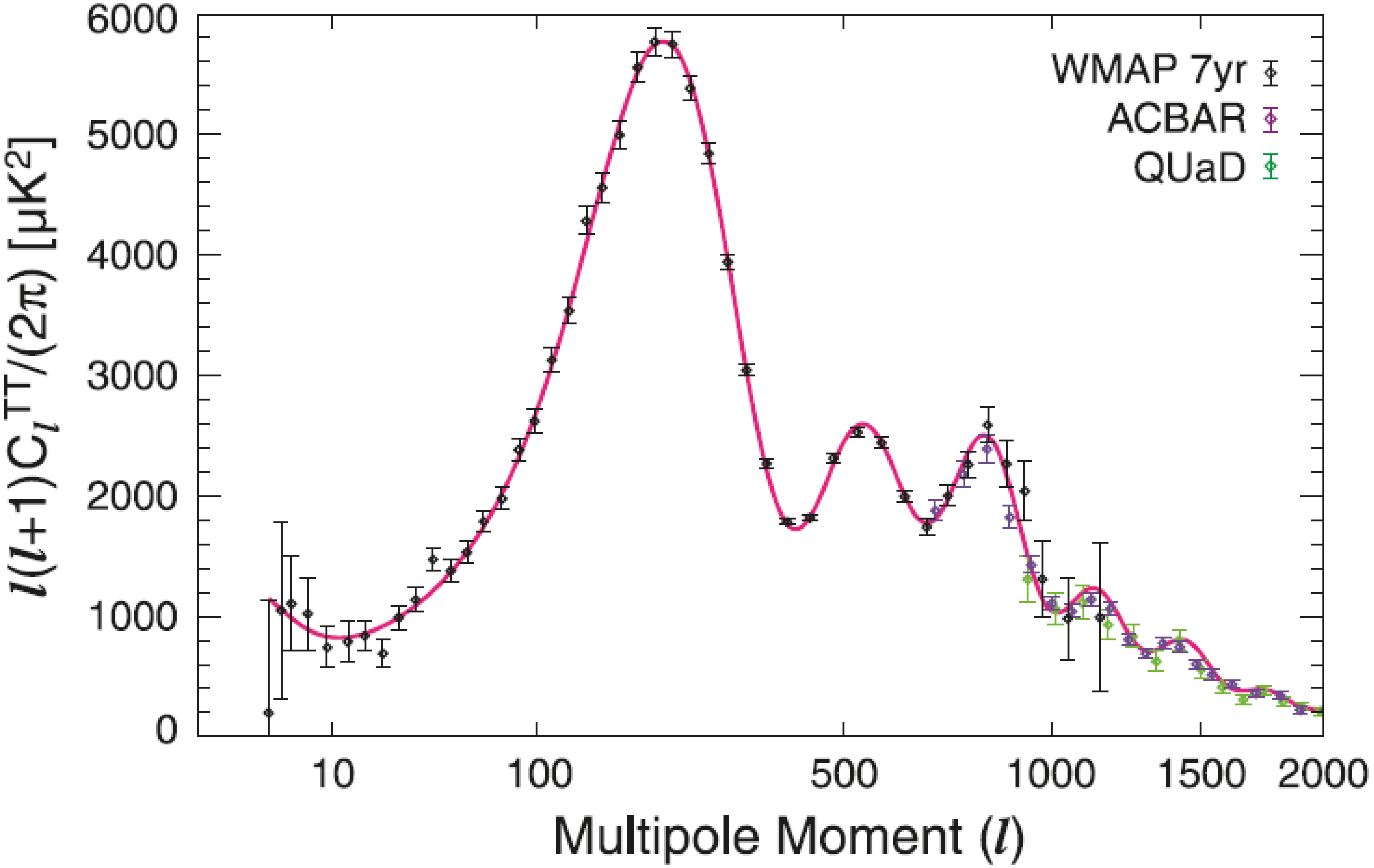
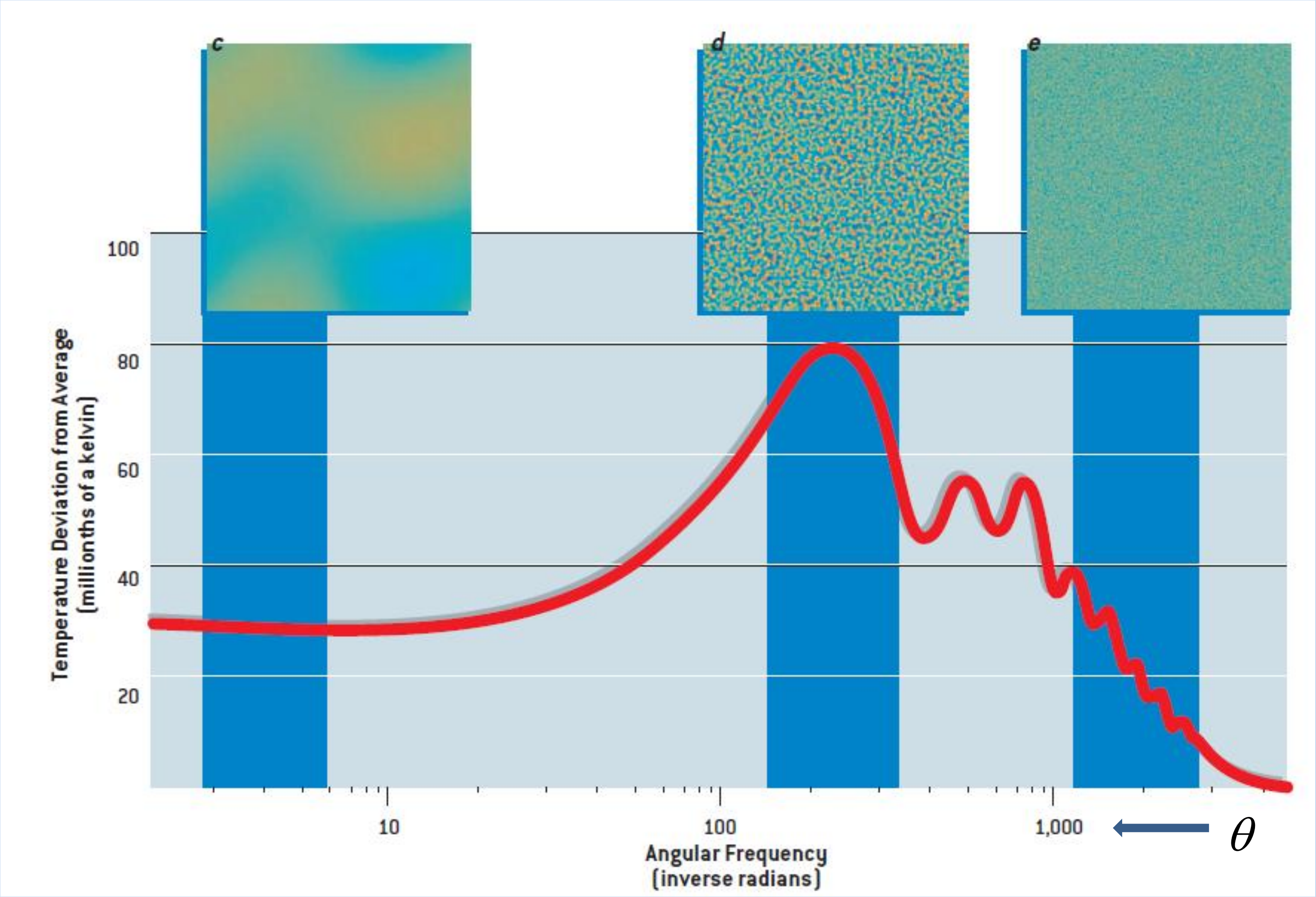
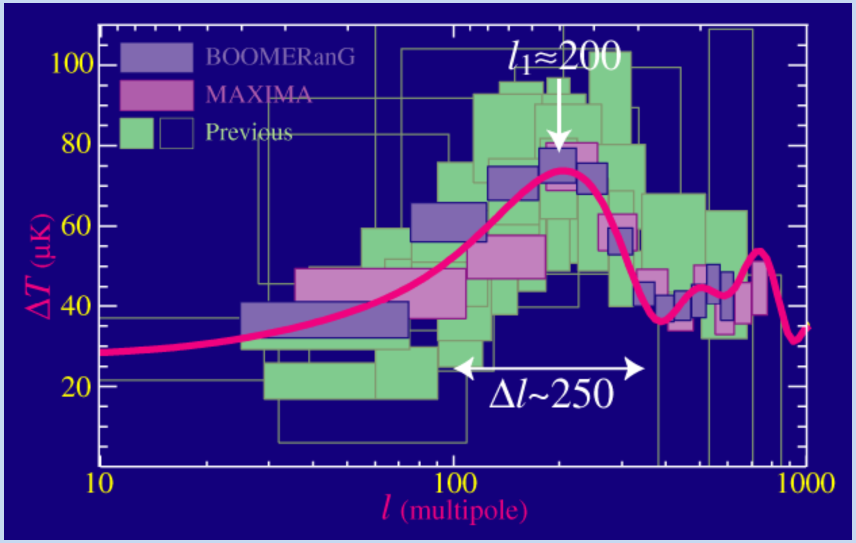


FIG. 7.— The *WMAP* 7-year temperature power spectrum (Larson et al. 2010), along with the temperature power spectra from the ACBAR (Reichardt et al. 2009) and QUaD (Brown et al. 2009) experiments. We show the ACBAR and QUaD data only at $l \geq 690$, where the errors in the *WMAP* power spectrum are dominated by noise. We do not use the power spectrum at $l > 2000$ because of a potential contribution from the SZ effect and point sources. The solid line shows the best-fitting 6-parameter flat ΛCDM model to the *WMAP* data alone (see the 3rd column of Table 1 for the maximum likelihood parameters).

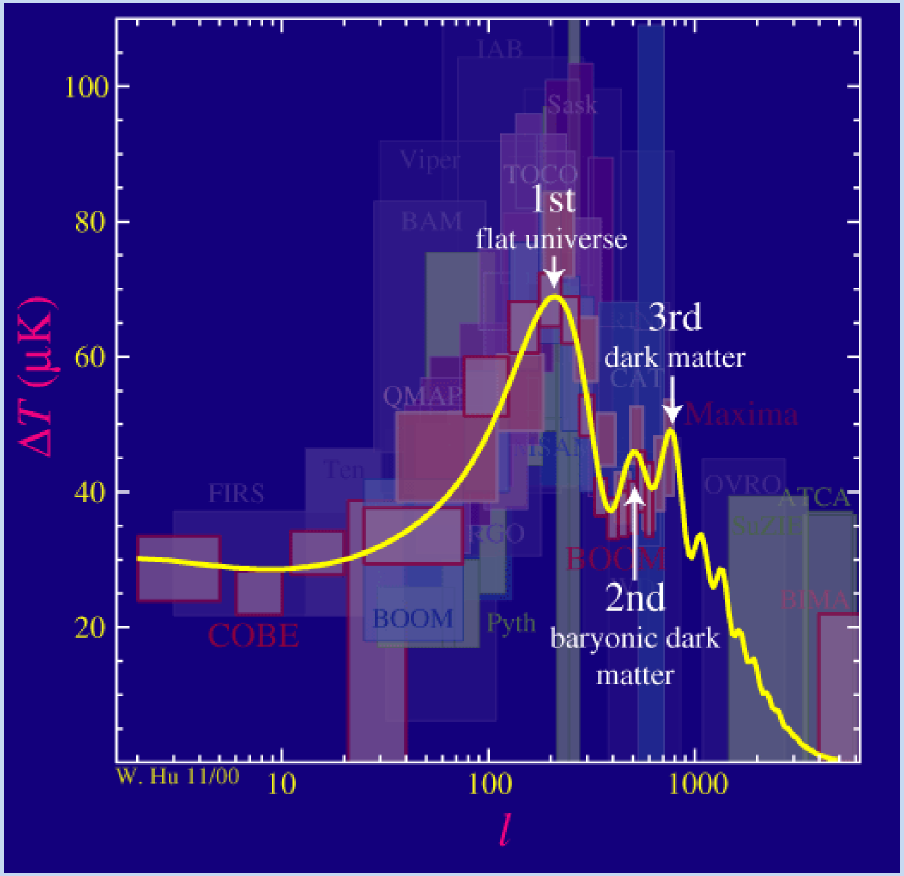
Температурните вариации са най-силно изразени за мащаби ~ 1° , за големи мащаби ~ 30 ° (c) и малки – 0.1 ° (e) не така значими.



2000 Boomerang и Maxima експерименти измерват първия максимум.
Изключителното добро съгласие
между формата на измерения максимум и предсказанията от теорията,
базирана на звукови вълни
от пертурбациите в инфлационния стадий,
е триумф на СКМ.



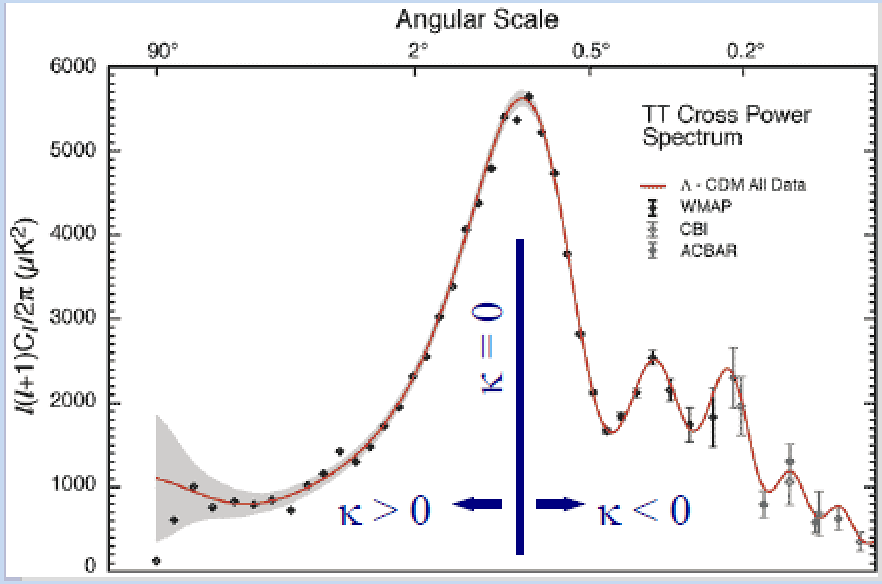
Положението на максимумите основно зависи от кривината. С намаляване на кривината максимумите се изместват към по-малки ъгли (по-големи мултиполи ***l***) докато формата им се запазва.
Формата зависи от физичната плътност на материята и барионите. Отсъствието на тъмна енергия играе малка роля в положението на максимумите.



Резултати:

• Измереното положение на първият максимум указва на плоска Вселена.

Можем до определим пълната енергия от измервания на пространствената кривина: $\Omega = 1 + k / H^2R^2$



КМФ има максимум на флуктуациите на определено разстояние от нас ~ 380 000 г. Измервайки съответния му ъглов размер можем да определим геометрията на пространството. Позицията на максимума е мерило за кривината.

От наблюдения: $\theta_{peak} = 1°$

следователно: $\Omega = 1.0$

Понеже $\Omega_M \sim 0.3$ то

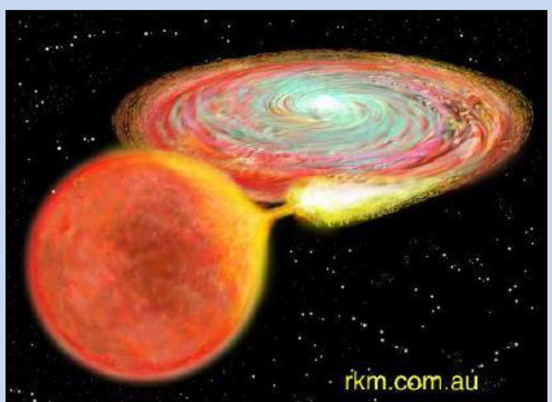
съществува Тъмна Енергия

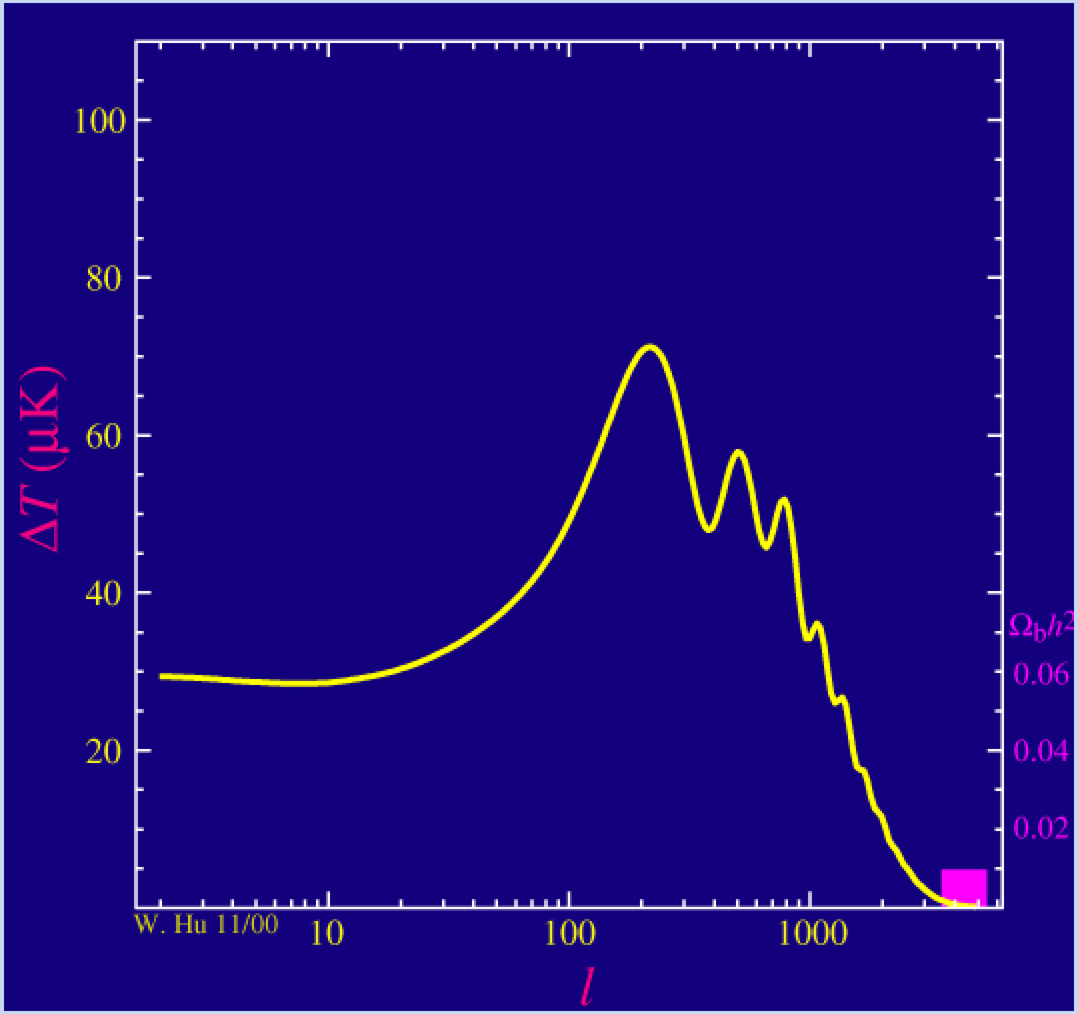
$\Omega_{DE} \sim 0.7$

студена, еднородно разпределена !!

- Наличие на тъмна енергия ТЕ необходима за съгласие между наблюдателните данни . Необходимото количесво ТЕ съвпада с ТЕ необходима за обяснение на резултатите от SN звезди.

Наблюденията на SNIa в далечни г-ки указват на ускорено разширение - наличие на Λ

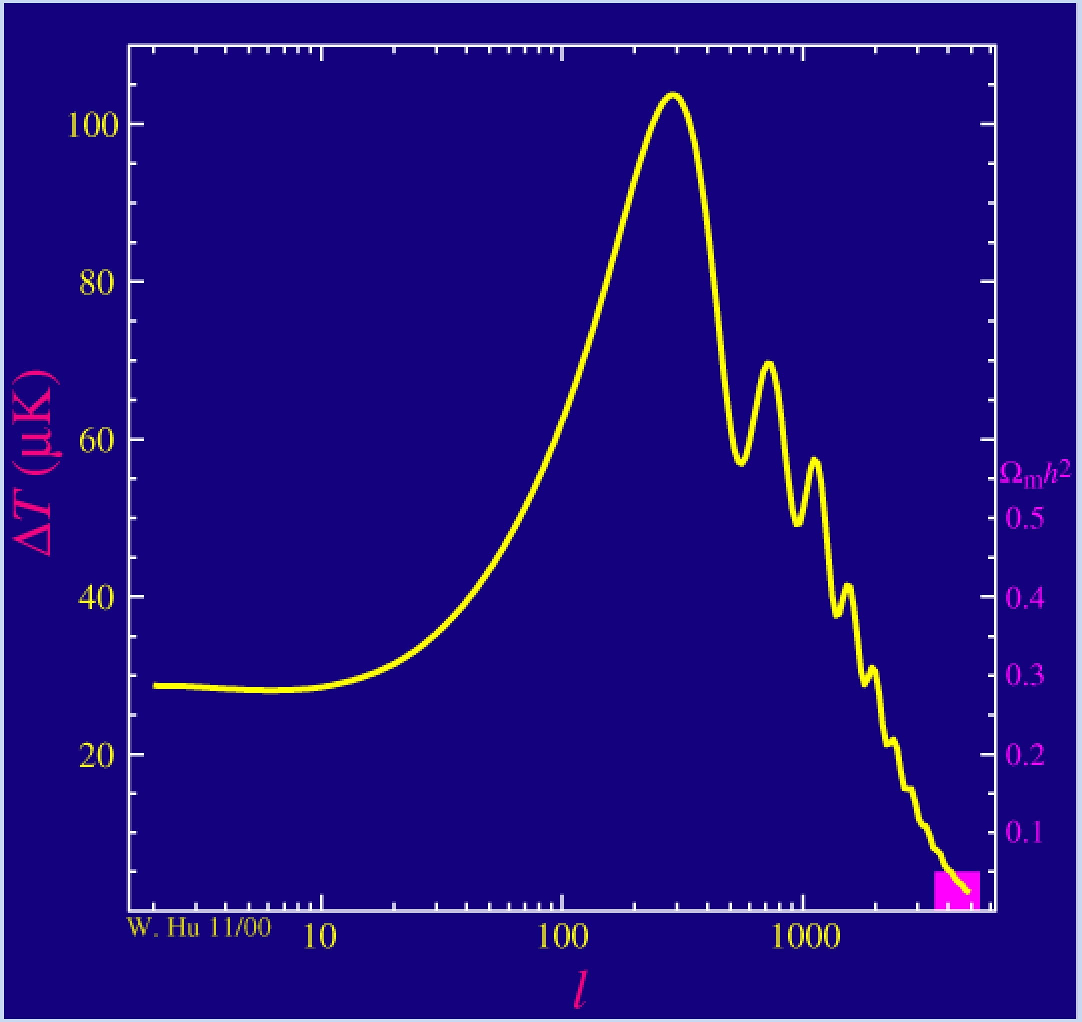




Изменение на барионната плътност изменя съотношението между четни и нечетни максимуми

Courtesy Wayne Hu – *http://background.uchicago.edu*

Peaks and Matter

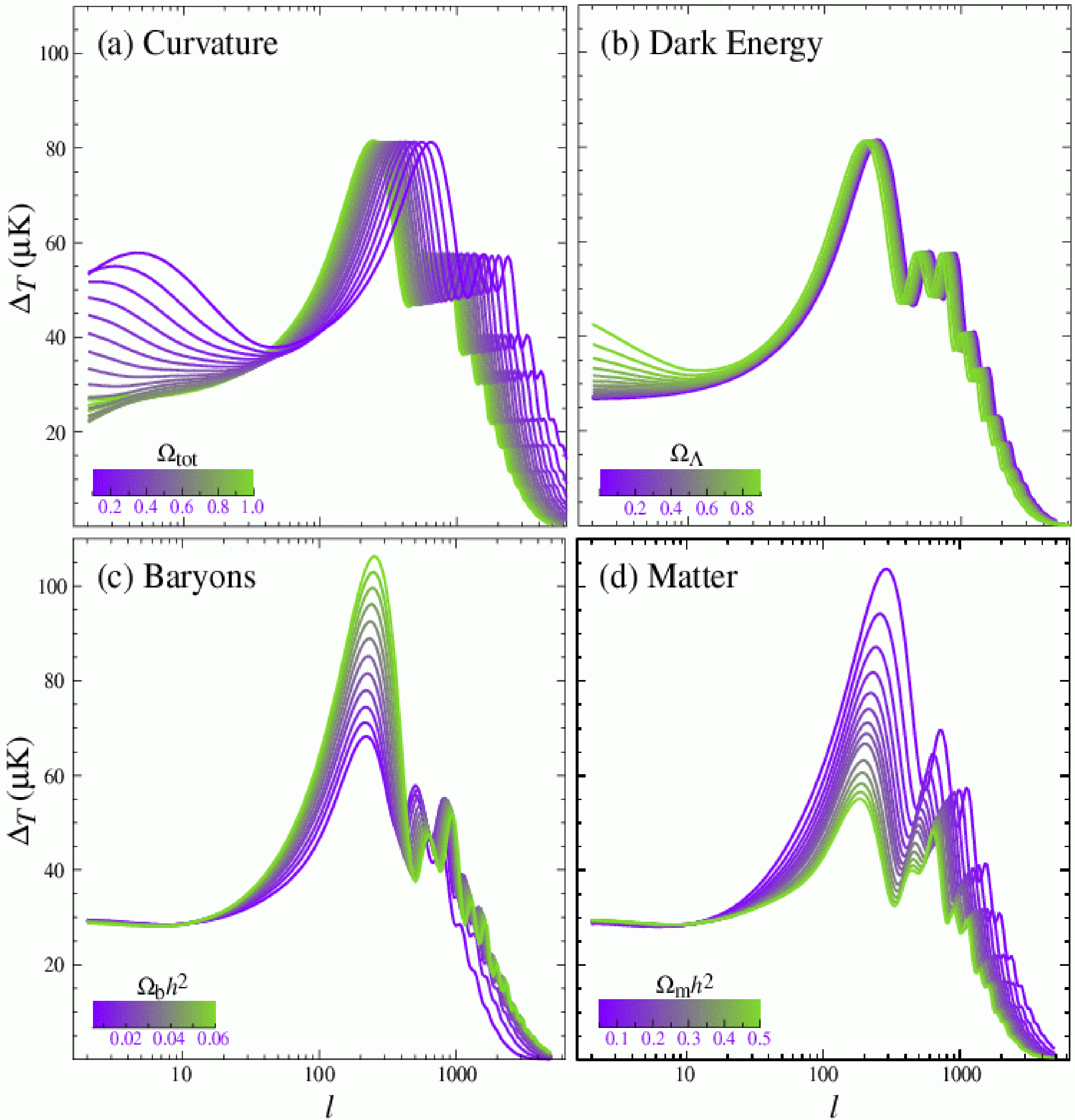


Changing dark matter density also changes peaks…

- Location and height of acoustic peaks
  - determine values of cosmological parameters
- Relevant parameters
  - curvature of Universe (e.g. open, flat, closed)
  - dark energy (e.g. cosmological constant)
  - amount of baryons (e.g. electrons & nucleons)
  - amount of matter (e.g. dark matter)

Courtesy Wayne Hu – *http://background.uchicago.edu*

Изключителното добро съгласие между формата на измерените максимуми и предсказанията от теорията, базирана на звукови вълни от пертурбациите в инфлационния стадий, е триумф на СКМ.



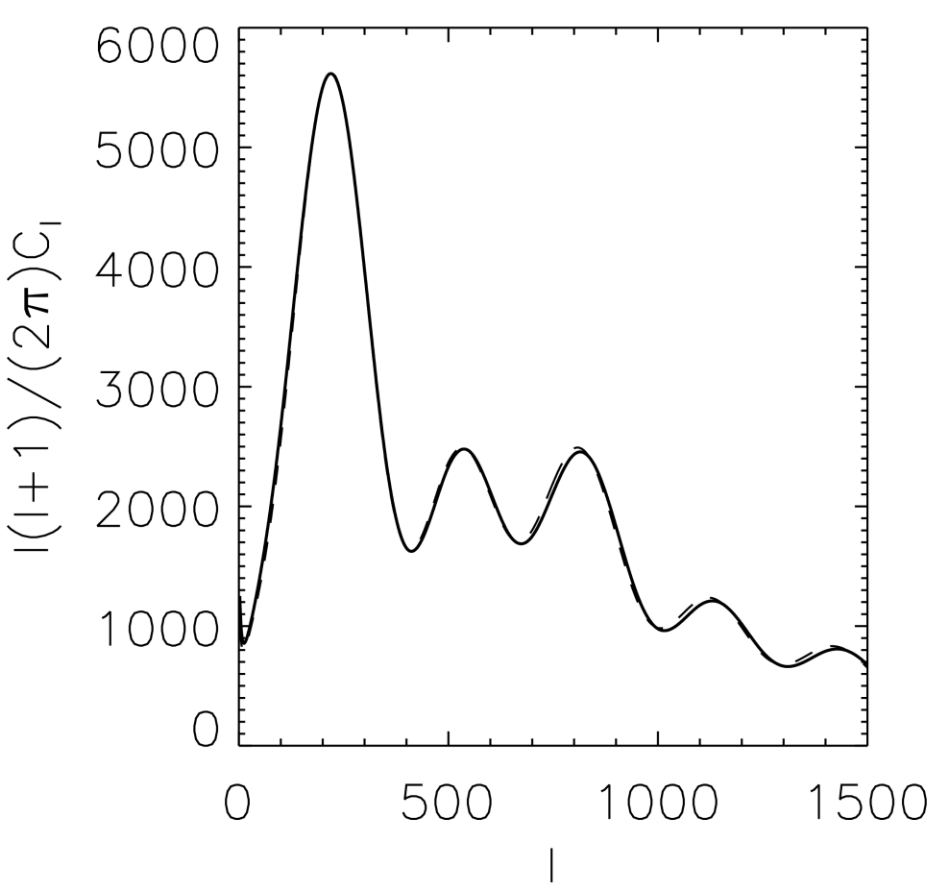
How comparing the CMB and galaxy surveys constrains the neutrino mass.

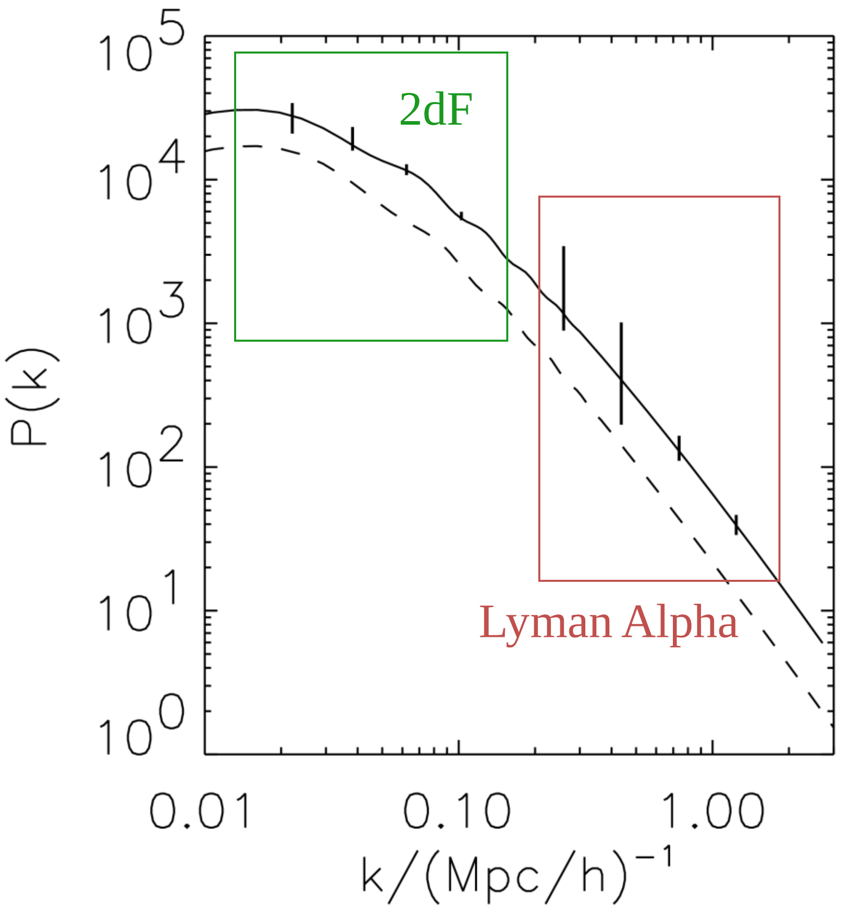
Massive neutrinos can hide in the CMB…

Solid: h=0.71 neutrino density=0

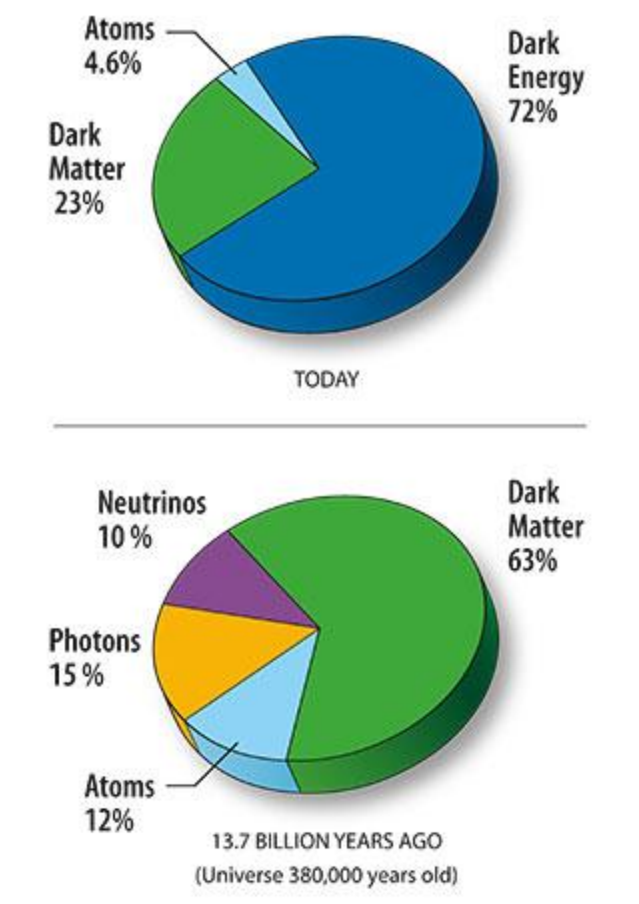
Dashed: h=0.60 neutrino density=0.02

... but at low redshift they are no longer relativistic and have a big effect on galaxy clustering.





WMAP



96% от плътността на енергията на Вселената е във форма недетектирана в лабораторни условия....!?

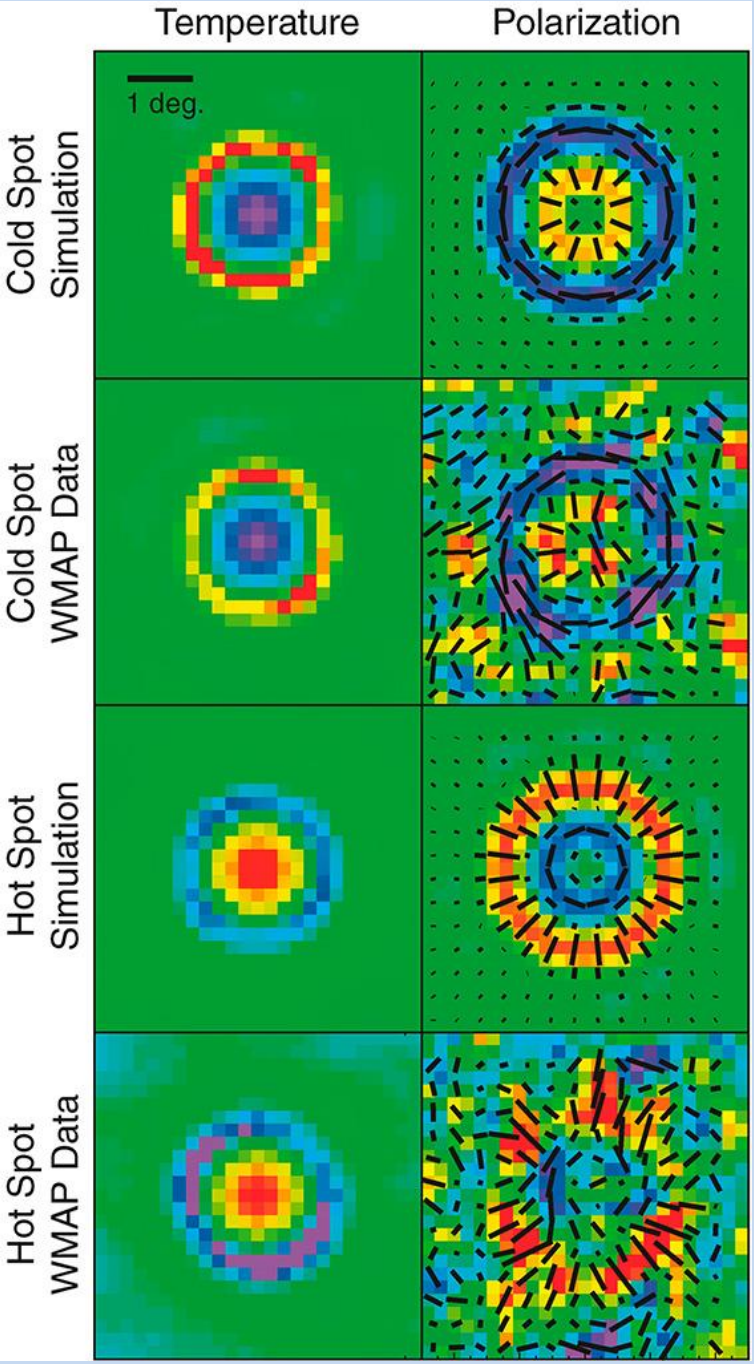
КМФ – бариометър на Вселената 4.6%
светещи бариони (0.1%)
ТВ 23.3% (1.3%)
ТЕ 72.1% (1.5%)

WMAP данните дават указания за свойствата на небарионното вещество: самодействие, маса, взаимодействие с обичайното вещество.

Неутриното не играе важна роля в образуването на структурите (иначе би забавило появата на първите звезди и галактики), но наличието на реликтовия неутринен фон е установено.

- Пълна карта на небето в микровълни с резолюция 0.2 градуса
- Поляризация на микровълновото лъчение на цялото небе.
- По- ранна рейонизация от очакваната - информация за първите галактики

- Кривина на пространството – плоско Евклидово с точност 1%
- Средната плътност е равна на критичната 9.9×10^{-30} g/cm^3 (5.9 p в m^3) (2% точност)
- Възраст на Вселената 13.73 милиарда години , 1% точност (0.12 млрд. г.)



Primordial helium Abundance[a]

	WMAP only	WMAP+ACBAR+QUaD
Y_p	< 0.51 (95% CL)	$Y_p = 0.326 \pm 0.075$ (68% CL)[b]

[a]See Section 4.8.

[b] The 95% CL limit is $0.16 < Y_p < 0.46$. For WMAP+ACBAR+QUaD+LRG+H_0, $Y_{He} = 0.349 \pm 0.064$ (68% CL) and $0.20 < Y_p < 0.46$ (95% CL).

WMAP 7-year Results

- **WMAP 7-year Results Released - January 26, 2010**
- The WMAP team has reported the first direct detection of pre-stellar helium, providing an important test of the big bang prediction.
- One of the key predictions of the hot big bang model is that most of the helium in the universe was synthesized in the hot early universe only a few minutes after the big bang. Previously, cosmologists studied old stars to infer the helium abundance before there were stars. WMAP data, in combination with smaller-scale data from the ACBAR and QUaD experiments, show the effects of helium in the microwave patterns on the sky indicating the presence of helium long before the first stars formed.
- WMAP now places 50% tighter limits on the standard model of cosmology (Cold Dark Matter and a Cosmological Constant in a flat universe), and there is no compelling sign of deviations from this model.
- WMAP has detected a key signature of inflation.
- WMAP data place tight constraints on the hypothesized burst of growth in the first trillionth of a second of the universe, called “inflation”, when ripples in the very fabric of space may have been created. The 7-year data provide compelling evidence that the large-scale fluctuations are slightly more intense than the small-scale ones, a subtle prediction of many inflation models.
- WMAP strongly constrains dark energy and geometry of the universe.
- The newly-released WMAP data are now sufficiently sensitive to test dark energy, providing important new information with no reliance on previous supernovae results. The combination of WMAP and other data** limits the extent to which dark energy deviates from Einstein's cosmological constant. The simplest model (a flat universe with a cosmological constant) fits the data remarkably well. The new data constrain the dark energy to be within 14% of the expected value for a cosmological constant, while the geometry must be flat to better than 1%. The simplest model: a flat universe with a cosmological constant, fits the data remarkably well.
- In more technical terms, for a flat universe, the dark energy "equation of state" parameter is -1.1 ± 0.14, consistent with the cosmological constant (value of -1). If the dark energy is a cosmological constant, then these data constrain the curvature parameter to be within -0.77% and +0.31%, consistent with a flat universe (value of 0).
- ** Includes: the current expansion rate of the universe (the Hubble constant) and the large-scale galaxy distribution (the baryon acoustic oscillations).
- WMAP places new constraints on the number of neutrino-like species in the early universe.
- Neutrinos are nearly massless elementary particles that move at or near the speed of light. They permeate the universe in large quantity but they interact very weakly with atomic matter. Nonetheless they leave an imprint on the microwave fluctuations and the new WMAP data together with other data** show that the effective number of neutrino-like species is 4.34 ± 0.87. The standard model of particle physics has 3.04 effective species of neutrinos.
- ** Includes: the current expansion rate of the universe (the Hubble constant) and the large-scale galaxy distribution (the baryon acoustic oscillations).
- WMAP has detected, with very high significance, temperature shifts induced by hot gas in galaxy clusters.
- The CMB temperature in the direction of known galaxy clusters is expected to be slightly cooler than the average CMB temperature, due to interactions between CMB photons and the gas in the clusters. This effect has been observed in aggregate by WMAP and is consistent with analogous observations by the South Pole Telescope. Both observations are in conflict with extrapolated X-ray observations of clusters (X-rays probe a smaller volume of cluster gas than the CMB observations) and with numerical simulations, which must be missing some of the complex gas physics in the outer regions of the clusters.
- WMAP has produced a visual demonstration that the polarization pattern around hot and cold spots follows the pattern expected in the standard model.
-

  Credit: NASA/WMAP Science Team
- The standard model predicts a specific linked pattern of temperature and polarization around hot and cold spots in the map. WMAP now sees the predicted pattern in the map, as shown in the figure.

The Age of the Universe

Structure of CMB fluctuations depend on the current density, the composition and the expansion rate. WMAP data with complimentary observations from other CMB experiments (ACBAR and CBI), we are able to determine an age for the universe closer to an accuracy of 1%.

The results are in agreement with the results deduced from structure formation studies.

$$H_0 t_0 \simeq \frac{2}{3}\left(0.7\Omega_m + 0.3 - 0.3\Omega_v\right)^{-0.3}$$

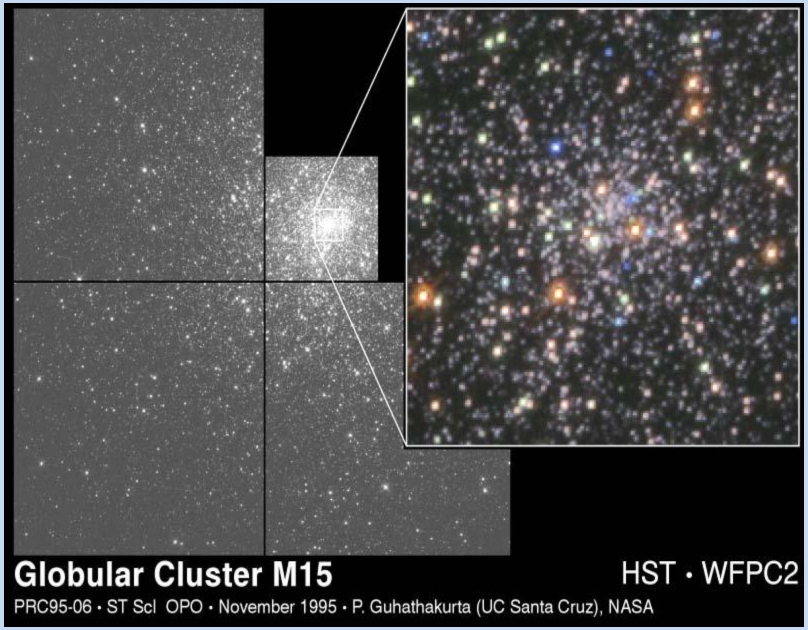
WMAP +CMB experiments (ACBAR and CBI), determine the age of the Universe with precision 1%: 13.73 billion y (0.12 billion y)

The result is in agreement with the age determined by structure studies, by globular cluster studies, etc.

The universe is at least as old as the oldest globular clusters (11-13 billion y) that reside in it.

Universe age - 13.7 billion years

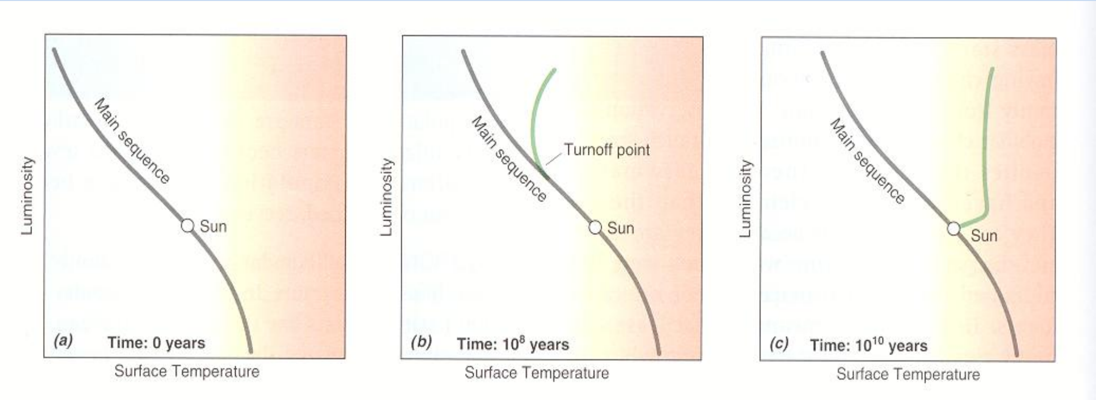
Oldest globular clusters age.



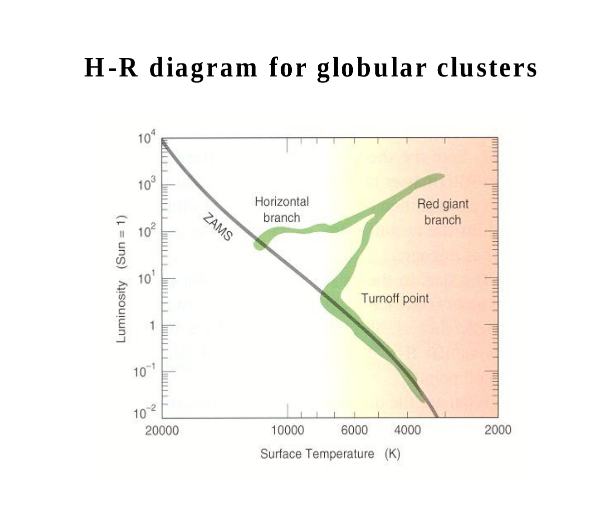
Life cycle of a star depends upon its mass

$$L \propto M^{4}$$

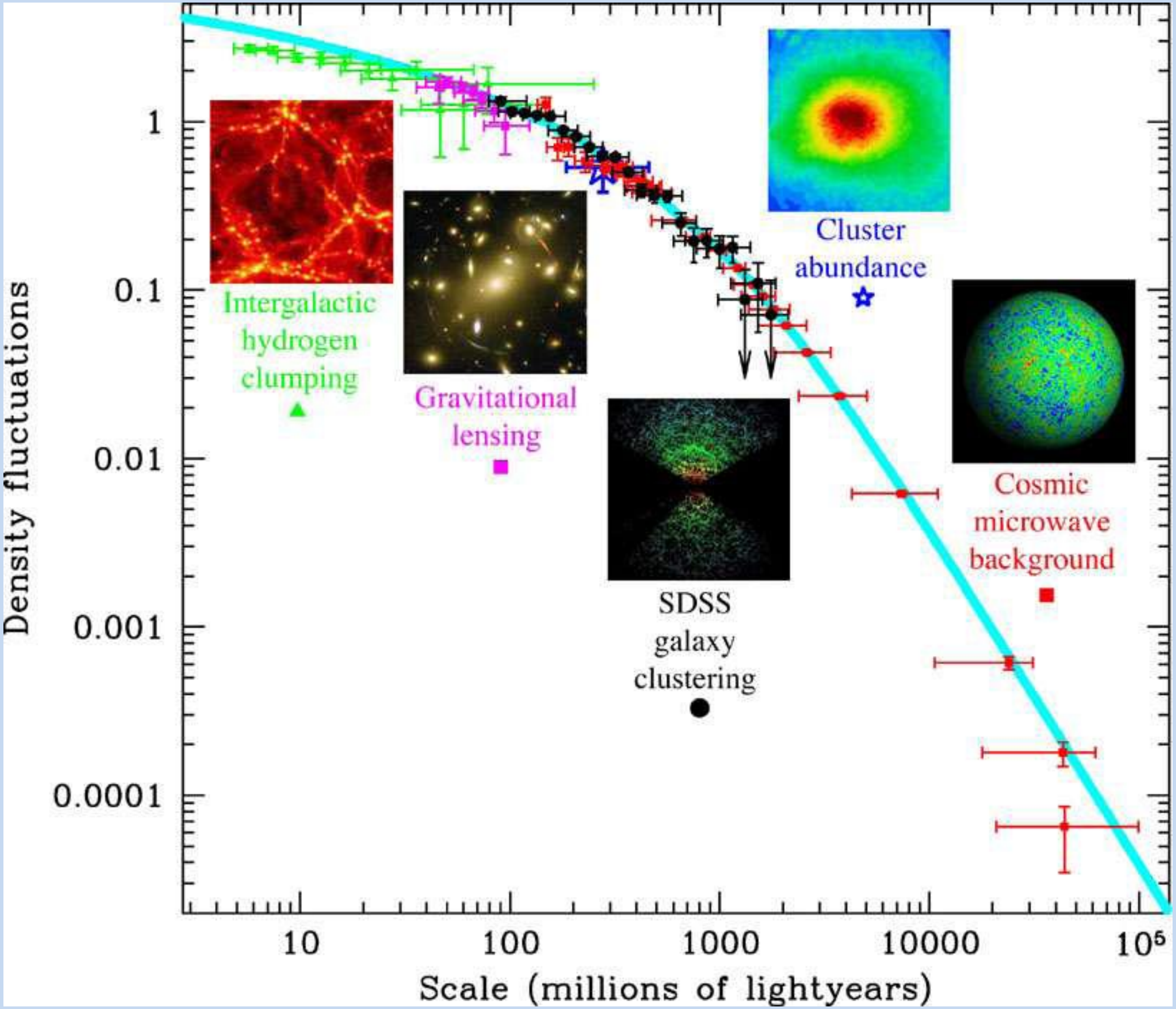
All of the stars in a globular cluster formed at roughly the same time: they can serve as cosmic clocks. The oldest globular clusters contain only stars less massive than 0.7 M. Observation suggests that the oldest globular clusters are between 11 and 13 billion years old.



Turn off points



Наблюдение на структури на различни мащаби: междугалактични Н облаци, галактики, купове и свръхкупове, наред с КМФ – информация за Вселената.



Динамиката на тези структури предоставя директна оценка както на пълната плътност на веществото, така и информация за спектъра на флуктуациите на различни машаби.

Малките пертурбации в CMB $\Delta T/T \sim 10^{-5}$ указват на флуктуациите на плътността в тази епоха, които впоследствие нарастват до наблюдаемите днес огромни галактики и купове от галактики.

Class	Parameter	*WMAP* 7-year ML[a]	*WMAP*+BAO+H_0 ML	*WMAP* 7-year Mean[b]	*WMAP*+BAO+H_0 Mean
Primary	$100\Omega_b h^2$	2.270	2.246	$2.258^{+0.057}_{-0.056}$	2.260 ± 0.053
	$\Omega_c h^2$	0.1107	0.1120	0.1109 ± 0.0056	0.1123 ± 0.0035
	Ω_Λ	0.738	0.728	0.734 ± 0.029	$0.728^{+0.015}_{-0.016}$
	n_s	0.969	0.961	0.963 ± 0.014	0.963 ± 0.012
	τ	0.086	0.087	0.088 ± 0.015	0.087 ± 0.014
	$\Delta^2_{\mathcal{R}}(k_0)$[c]	2.38×10^{-9}	2.45×10^{-9}	$(2.43 \pm 0.11) \times 10^{-9}$	$(2.441^{+0.088}_{-0.092}) \times 10^{-9}$
Derived	σ_8	0.803	0.807	0.801 ± 0.030	0.809 ± 0.024
	H_0	71.4 km/s/Mpc	70.2 km/s/Mpc	71.0 ± 2.5 km/s/Mpc	$70.4^{+1.3}_{-1.4}$ km/s/Mpc
	Ω_b	0.0445	0.0455	0.0449 ± 0.0028	0.0456 ± 0.0016
	Ω_c	0.217	0.227	0.222 ± 0.026	0.227 ± 0.014
	$\Omega_m h^2$	0.1334	0.1344	$0.1334^{+0.0056}_{-0.0055}$	0.1349 ± 0.0036
	$z_{\rm reion}$[d]	10.3	10.5	10.5 ± 1.2	10.4 ± 1.2
	t_0[e]	13.71 Gyr	13.78 Gyr	13.75 ± 0.13 Gyr	13.75 ± 0.11 Gyr

[a]Larson et al. (2010). "ML" refers to the Maximum Likelihood parameters.

[b]Larson et al. (2010). "Mean" refers to the mean of the posterior distribution of each parameter. The quoted errors show the 68% confidence levels (CL).

[c]$\Delta^2_{\mathcal{R}}(k) = k^3 P_{\mathcal{R}}(k)/(2\pi^2)$ and $k_0 = 0.002$ Mpc^{-1}.

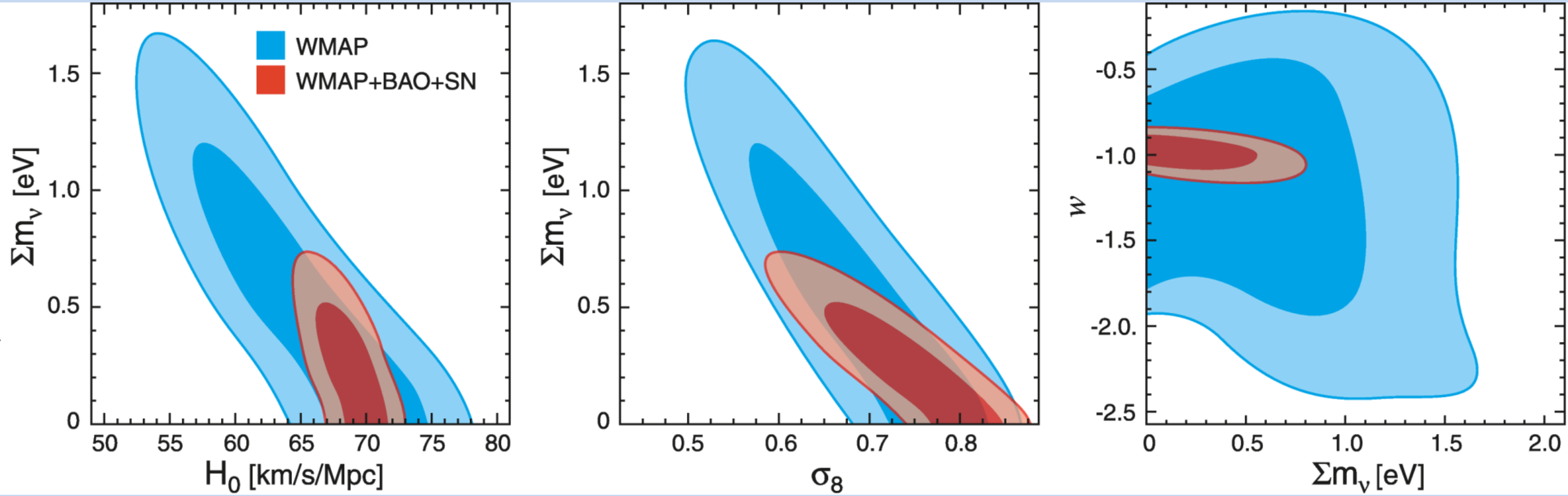
[d]"Redshift of reionization," if the universe was reionized instantaneously from the neutral state to the fully ionized state at $z_{\rm reion}$. Note that these values are somewhat different from those in Table 1 of Komatsu et al. (2009b), largely because of the changes in the treatment of reionization history in the Boltzmann code CAMB (Lewis 2008).

[e]The present-day age of the universe.

Cosmological parameters and neutrino

Fast moving neutrinos do not play any major role in the evolution of structure in the universe. They would have prevented the early clumping of gas in the universe, delaying the emergence of the first stars, in conflict with the new WMAP data.

Komatsu *et al*., 803.0547



Improvements in $N_{\rm eff}$: 7-year versus 5-year

Parameter	Year	*WMAP* only	*WMAP*+BAO+SN+*HST*	*WMAP*+BAO+H_0	*WMAP*+LRG+H_0
$z_{\rm eq}$	5-year	3141^{+154}_{-157}	3240^{+99}_{-97}		
	7-year	3145^{+140}_{-139}		3209^{+85}_{-89}	3240 ± 90
$\Omega_m h^2$	5-year	$0.178^{+0.044}_{-0.041}$	0.160 ± 0.025		
	7-year	$0.184^{+0.041}_{-0.038}$		0.157 ± 0.016	$0.157^{+0.013}_{-0.014}$
$N_{\rm eff}$	5-year	> 2.3 (95% CL)	4.4 ± 1.5		
	7-year	> 2.7 (95% CL)		$4.34^{+0.86}_{-0.88}$	$4.25^{+0.76}_{-0.80}$

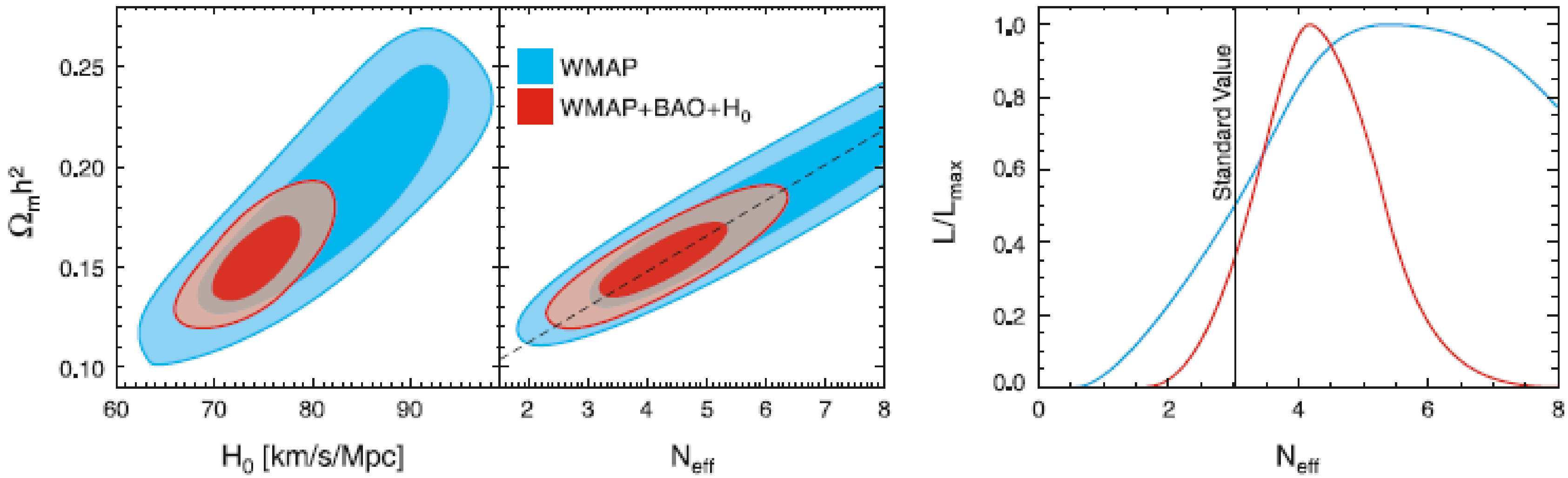


Fig. 9.— Constraint on the effective number of neutrino species, $N_{\rm eff}$. (Left) Joint two-dimensional marginalized distribution (68% and 95% CL), showing how a better determination of H_0 improves a limit on $\Omega_m h^2$. (Middle) A correlation between $N_{\rm eff}$ and $\Omega_m h^2$. The dashed line shows the line of correlation given by equation (58). A better determination of H_0 improves a limit on $\Omega_m h^2$ which, in turn, improves a limit on $N_{\rm eff}$. (Right) One-dimensional marginalized distribution of $N_{\rm eff}$ from *WMAP*-only and *WMAP*+BAO+H_0. The 68% interval from *WMAP*+BAO+H_0, $N_{\rm eff} = 4.34^{+0.86}_{-0.88}$, is consistent with the standard value, 3.04, which is shown by the vertical line.

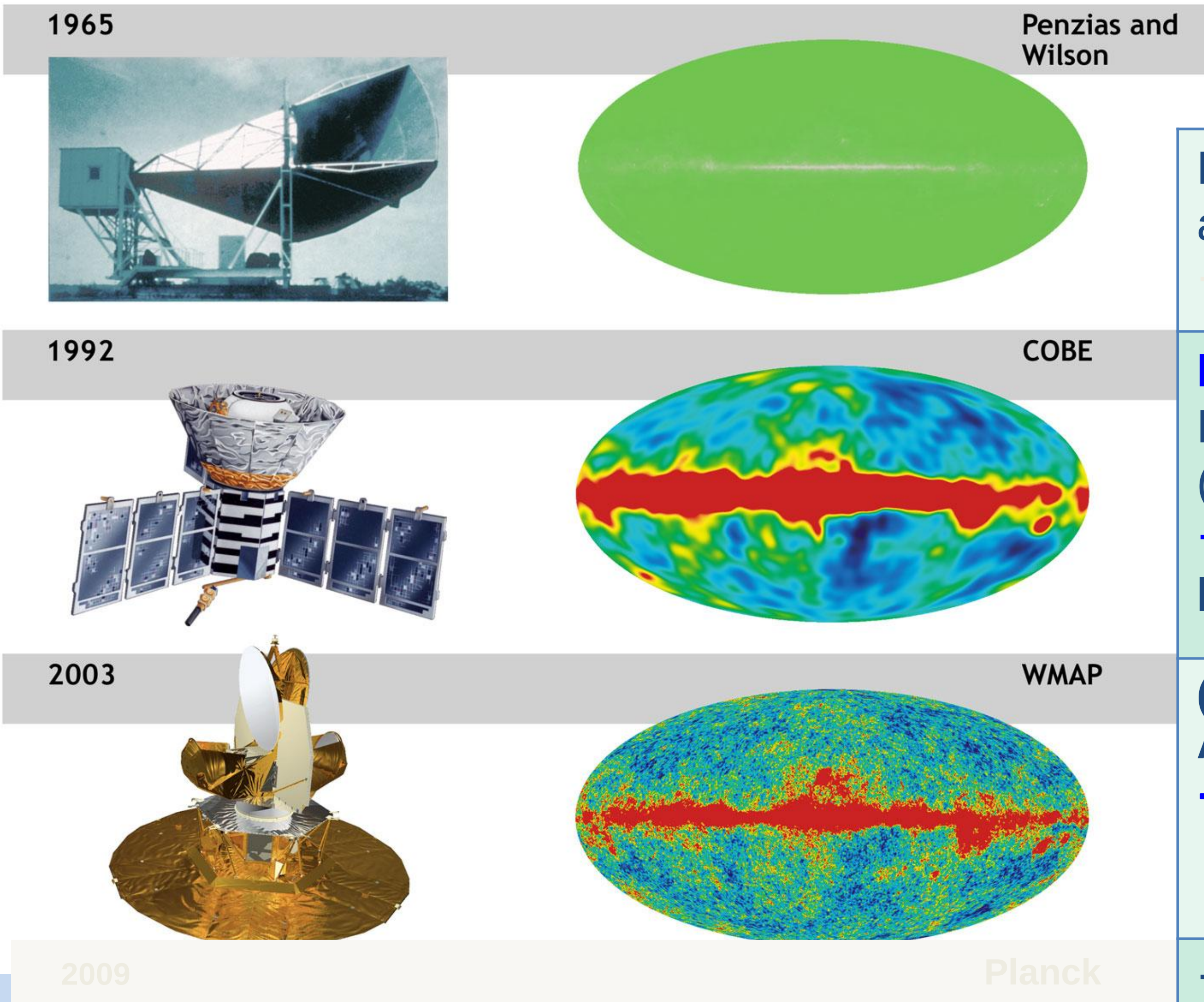
PRIMORDIAL HELIUM ABUNDANCE[a]

	WMAP only	*WMAP*+ACBAR+QUaD
Y_p	< 0.51 (95% CL)	$Y_p = 0.326 \pm 0.075$ (68% CL)[b]

[a]See Section 4.8.

[b] The 95% CL limit is $0.16 < Y_p < 0.46$. For *WMAP*+ACBAR+QUaD+LRG+H_0, $Y_{\rm He} = 0.349 \pm 0.064$ (68% CL) and $0.20 < Y_p < 0.46$ (95% CL).

Cosmic Microwave Background Radiation Overview



The oldest light in universe

Discovered the remnant afterglow from the **Big Bang**
→ **2.7 K**

Blackbody radiation, Discovered the patterns (**anisotropy**) in the afterglow.
→ **angular scale ~ 7°** at a level $\Delta T/T$ of 10^{-5}

(Wilkinson Microwave Anisotropy Probe):
→ **angular scale ~ 15'**

→ **angular scale ~ 5',**
$\Delta T/T \sim 2\times10^{-6}$, 30~867 Hz

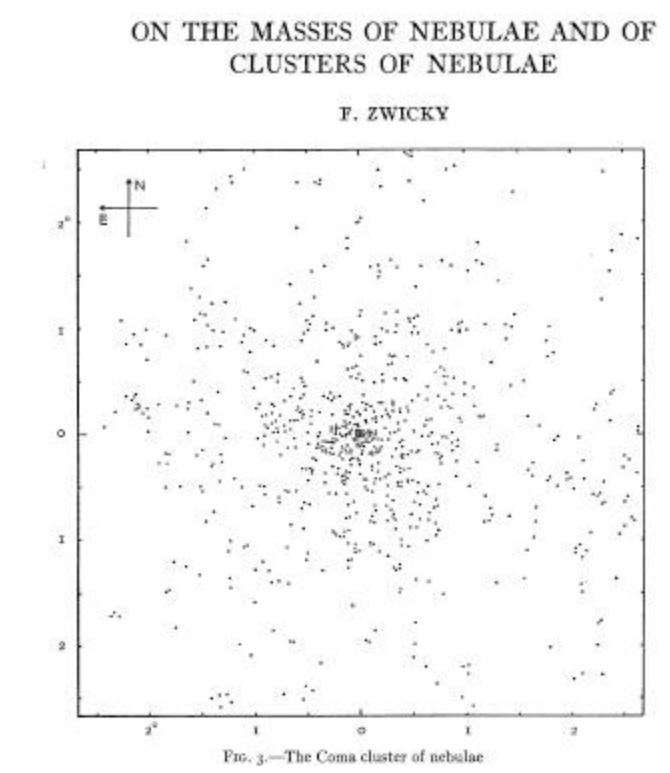
The Universe Secrets

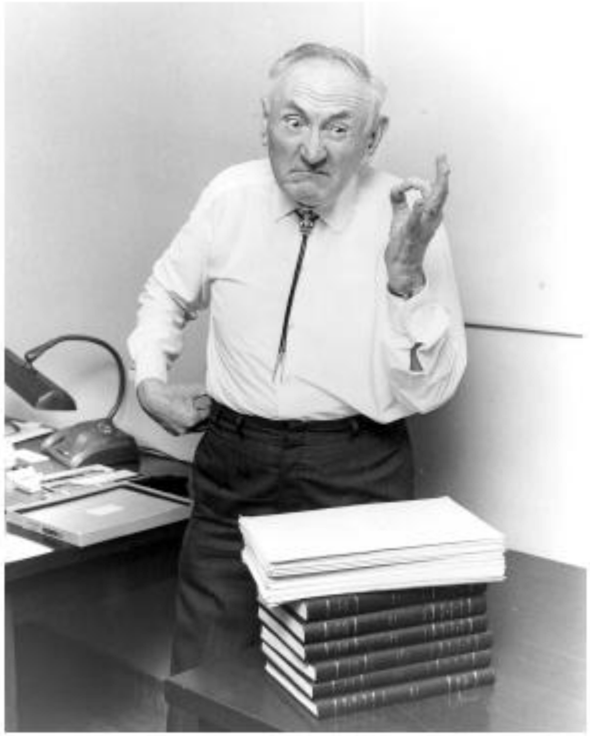
Dark Matter, Dark Energy

matter-antimatter asymmetry

inflation

Наблюдателни свидетелства и теоретични указания





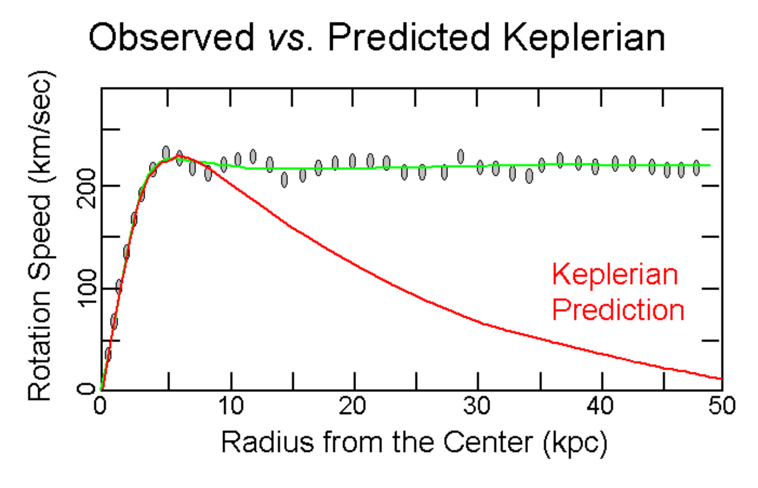
"Проблема за скритата маса"
1933, Fritz Zwicky

F. Zwicky открива указания за ТВ в купове от галактики, изучавайки скоростите на галактиките.

Dark Matter

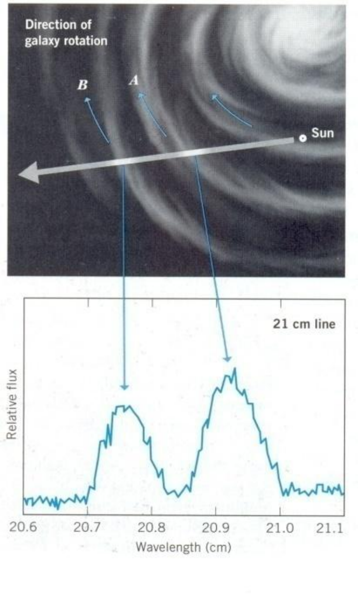
Observational Indications

Rotation Curves: The dependence of the velocity of rotation of an object on its distance from the galactic center.



The mass inferred for galaxies is roughly ten times larger than the mass that can be associated with stars, gas and dust in a Galaxy.

$\Omega_{\rm DM} \gtrsim 0.1,$



Radio and optical observations of gas and stars in galaxies enable us to determine the distribution of mass in these systems

DM at galactic and galaxy cluster scale

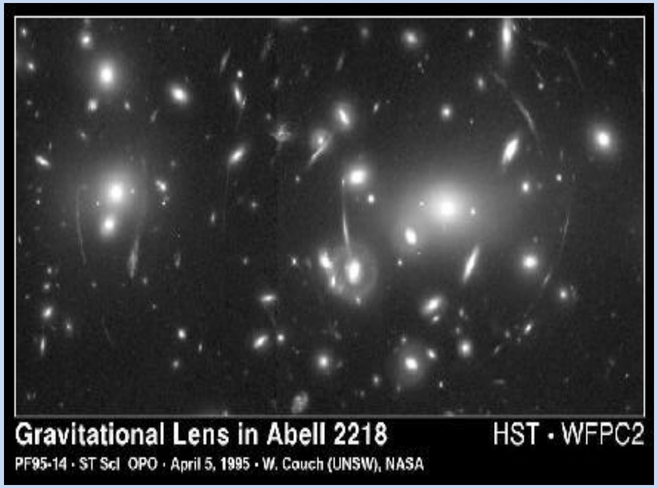
F. Zwicky discovered the presence of DM on a much larger scale through his studies of large velocitieas in galactic clusters. Recent measurements:

galaxy clusters (and binary galaxies) have M/L ratios up to 300.

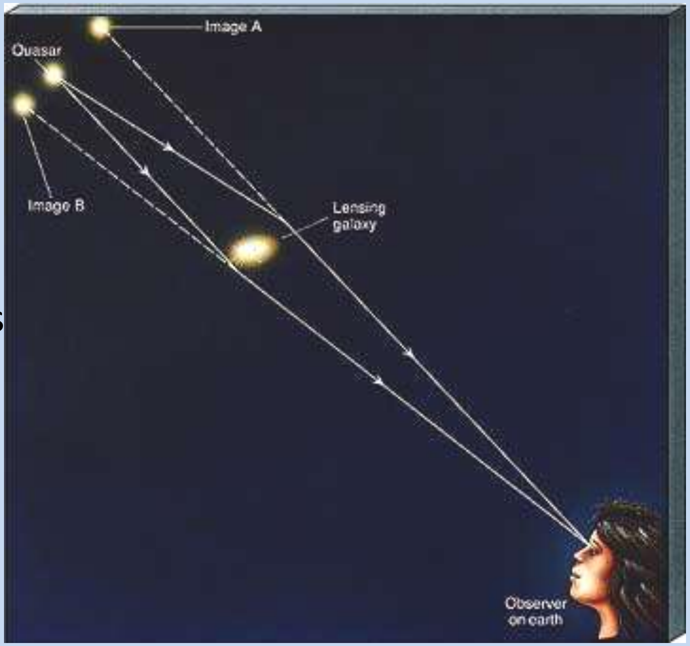
Gravitational Lensing

This mass discrepancy confirmed by gravitational lensing.

By measuring how the background galaxies are distorted by the foreground cluster the cluster mass is measured. It is more than ten times larger than the inferred mass in visible stars, gas and dust. $\Omega_{\rm DM} \simeq 0.2$



Gravitational lensing, predicted by GR, occurs when light traveling toward us from a distant galaxy is magnified and distorted as it encounters a massive object between the galaxy and us.
The massive objects that create the lenses are usually huge clusters of massive galaxies. Gravitational lensing allows to measure the mass of the object creating the lense. The angle of deviation is proportional to the mass of the lensing system and provides information about DM distribution.

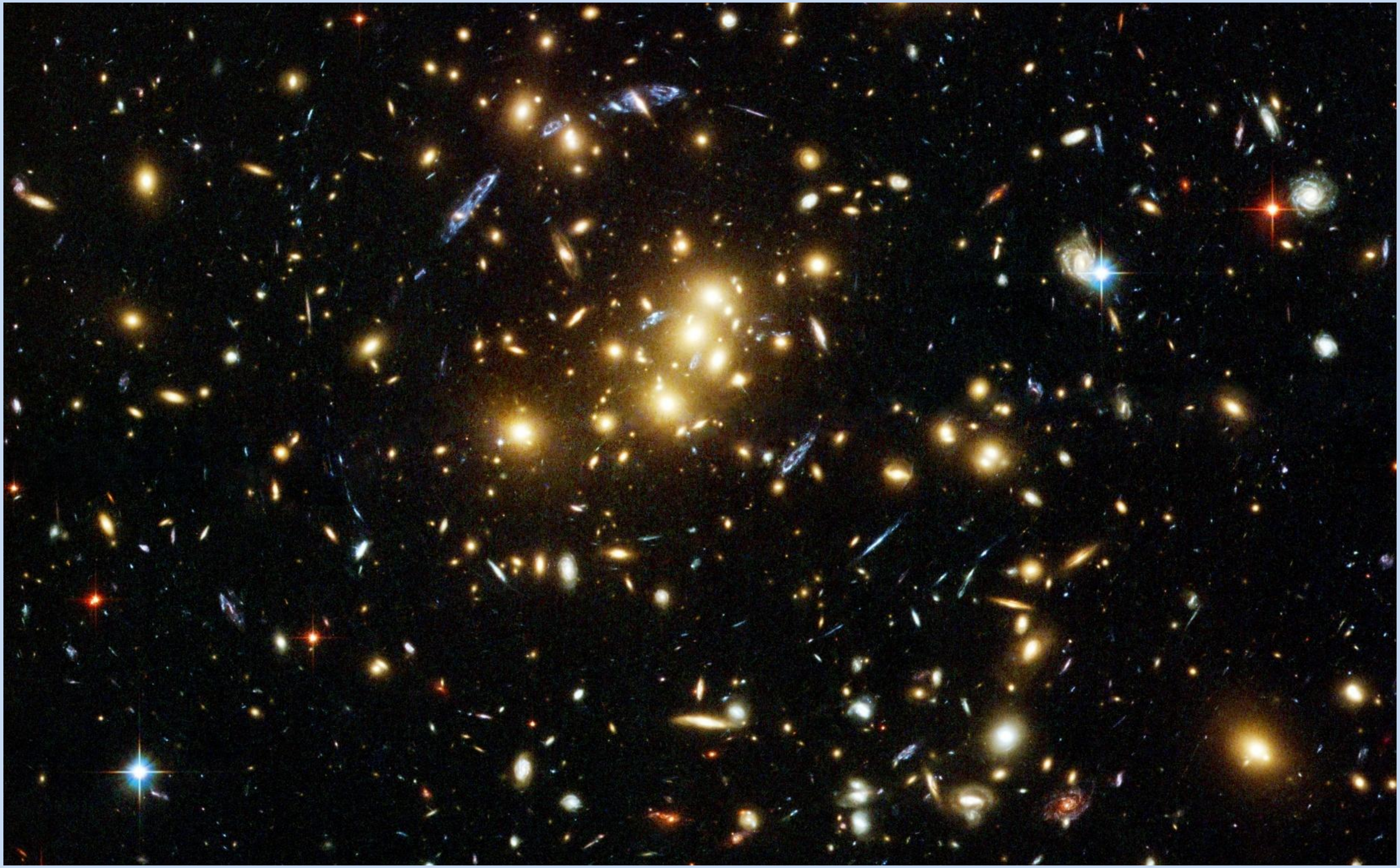


COSMOS project: to survey a single 1.6-square-degree field of sky (nine times the area of the full Moon) with several space-based and Earth-based observatories, namely Hubble Space Telescope, Spitzer Space Telescope, XMM-Newton spacecraft, Chandra X-ray Observatory, Very Large Telescope (VLT), Subaru Telescope, Canada-France-Hawaii Telescope.

Astronomers using Hubble Space Telescope and ground-based telescopes have compiled a large catalog of gravitational lenses in the distant universe. The catalog contains 67 new gravitationally lensed galaxy images found around massive elliptical and lenticular-shaped galaxies. If this sample is representative, there would be nearly half a million similar gravitational lenses over the whole sky.

The study of the gravitational lenses gives an opportunity to probe DM distribution around galactic lenses.

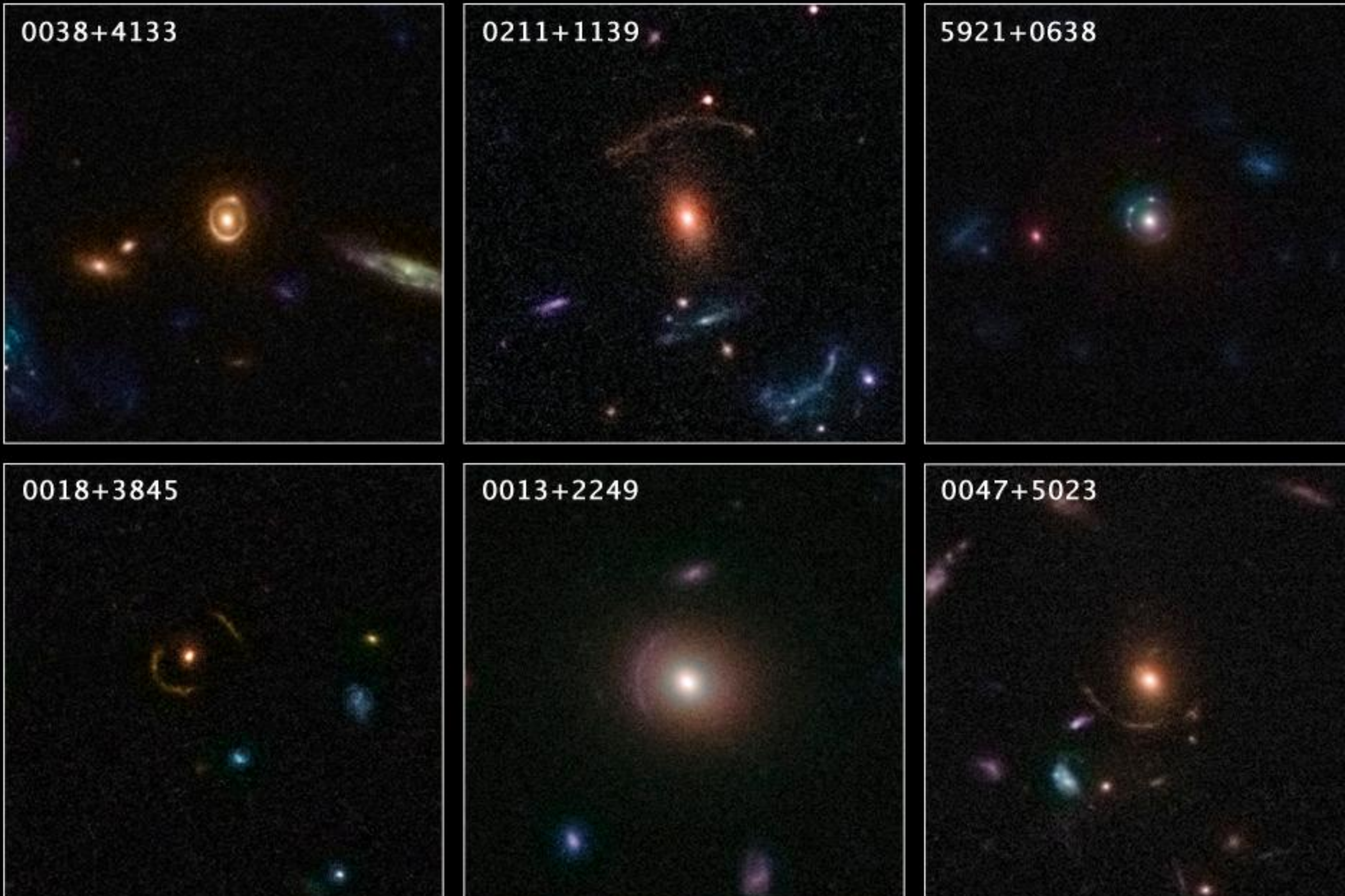
Gravitational Lenses



HST image presenting a rich cluster of galaxies (in yellow) , at 5 billions ly, distorting the light from far away galaxies situated behind it, seen as blue arcs.

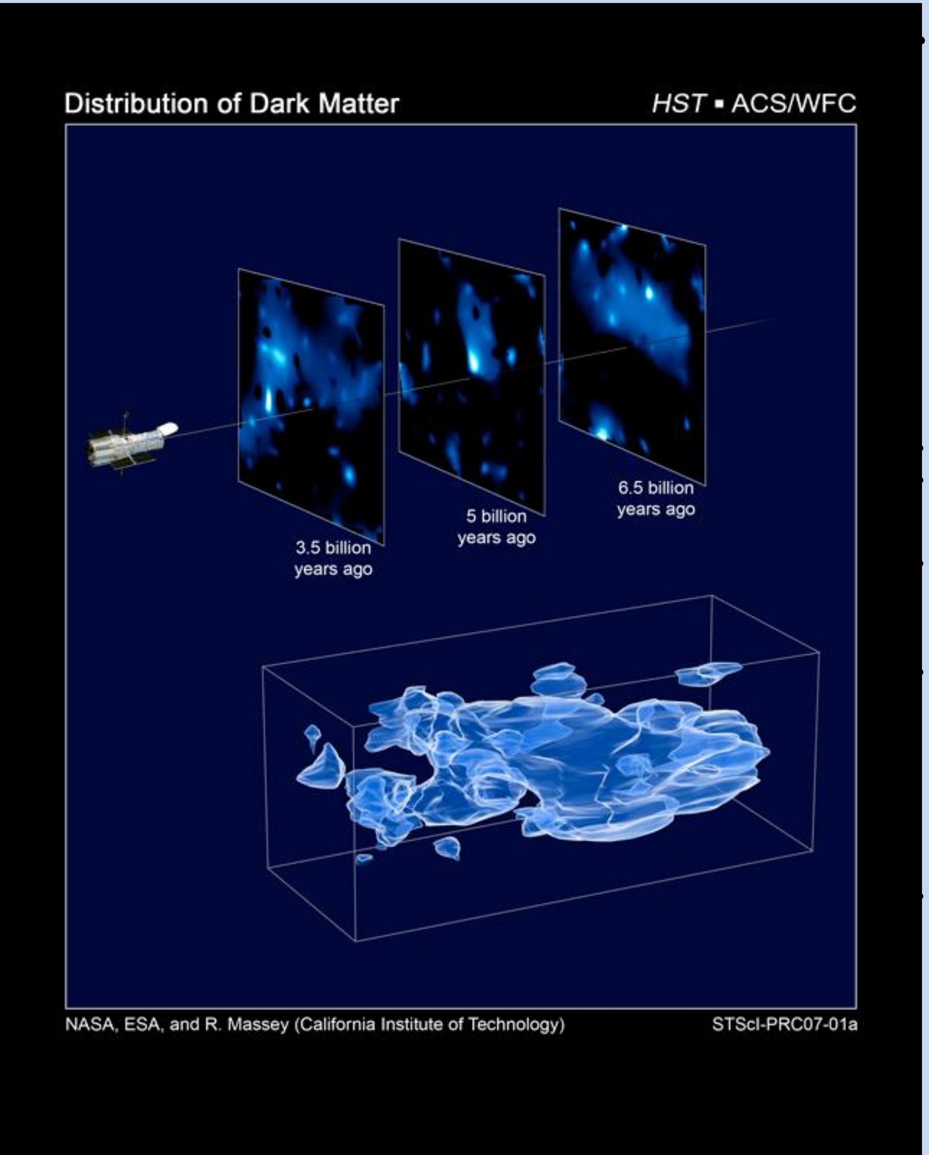
The form and the distribution of arcs show that the shining matter in the cluster is not enough to explain the distortions, i.e. the cluster contains big quantity of DM.

Gravitational Lenses in the COSMOS Survey *Hubble Space Telescope* ▪ ACS/WF



NASA, ESA, C. Faure (Zentrum für Astronomie, University of Heidelberg) and
J.-P. Kneib (Laboratoire d'Astrophysique de Marseille) STScI-PRC08-0

A 3D map of DM in the Universe

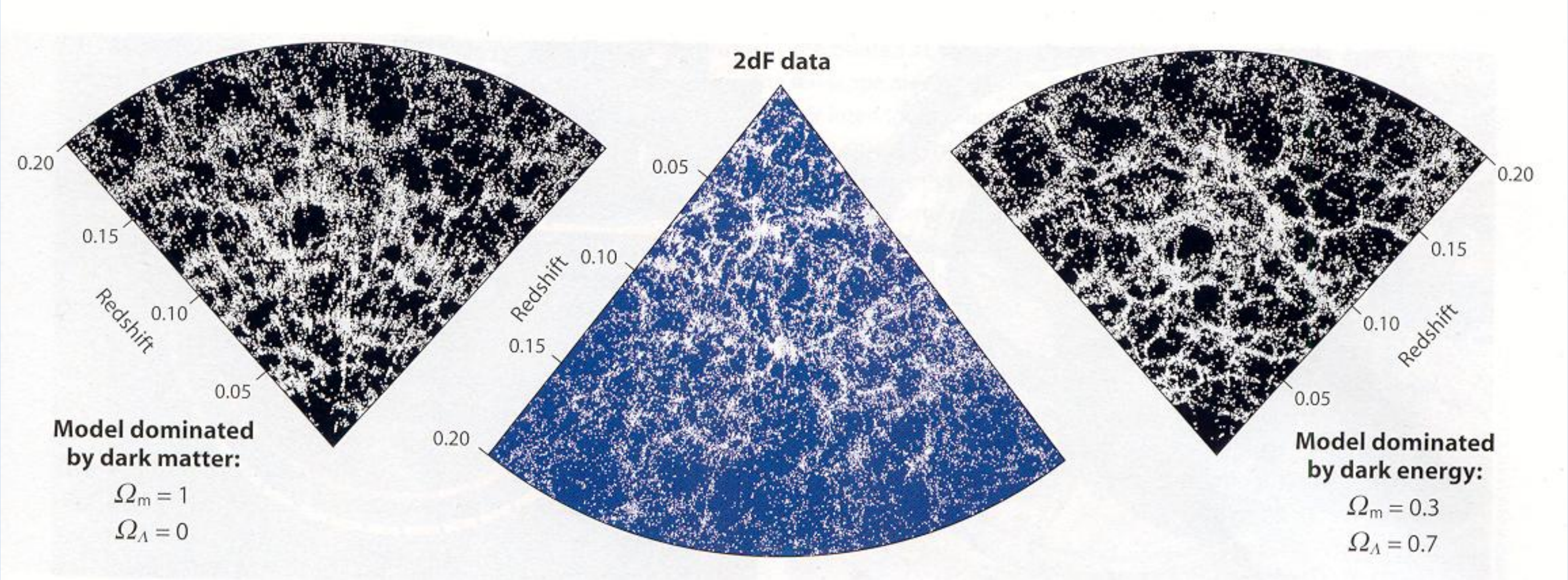


- The map reveals a loose network of dark matter filaments, gradually collapsing under the relentless pull of gravity, and growing clumpier over time. This confirms theories of how structure formed in our evolving universe, which has transitioned from a comparatively smooth distribution of matter at the time of the big bang. The dark matter filaments began to form first and provided an underlying scaffolding for the subsequent construction of stars and galaxies from ordinary matter. Without dark matter, there would have been insufficient mass in the universe for structures to collapse and galaxies to form.

- [Top] - Three slices through the evolving distribution of DM.
- This is calibrated by measuring the cosmological redshift of the lensing galaxies used to map the dark matter distribution, and binning them into different time/distance "slices".
- Each panel represents an area of sky nine times the angular diameter of the full Moon. Note that this fixed angle means that the survey volume is a really a cone, and that the physical area of the slices increases (from 19 Mpc on a side to 31 Mpc on a side) from left to right.
- [Bottom] - When the slices across the universe and back into time are combined, they make a 3D map of DM in the universe. The three axes of the box correspond to sky position (in right ascension and declination), and distance from the Earth increasing from left to right (as measured by cosmological redshift). Note how the clumping of the DM becomes more pronounced, moving right to left across the volume map, from the early universe to the more recent universe.

- The DM distribution was mapped with Hubble Space Telescope's survey of the universe, the Cosmic Evolution Survey ("COSMOS"). To compile the COSMOS survey, Hubble photographed 575 adjacent and slightly overlapping views of the universe using the Advanced Camera for Surveys' (ACS) Wide Field Camera onboard Hubble. It took nearly 1,000 hours of observations. The distances to the galaxies were determined from their spectral redshifts, using the Subaru telescope in Hawaii.

Galaxies' Distribution vers Theoretical Simulations



DM is required in order to enable gravity to amplify the small fluctuations in CMB enough to form the large-scale structures that we see in the universe today.

$$\Omega_\nu h^2 \leq 0.0076 \quad 95\%\ \mathrm{CL}$$

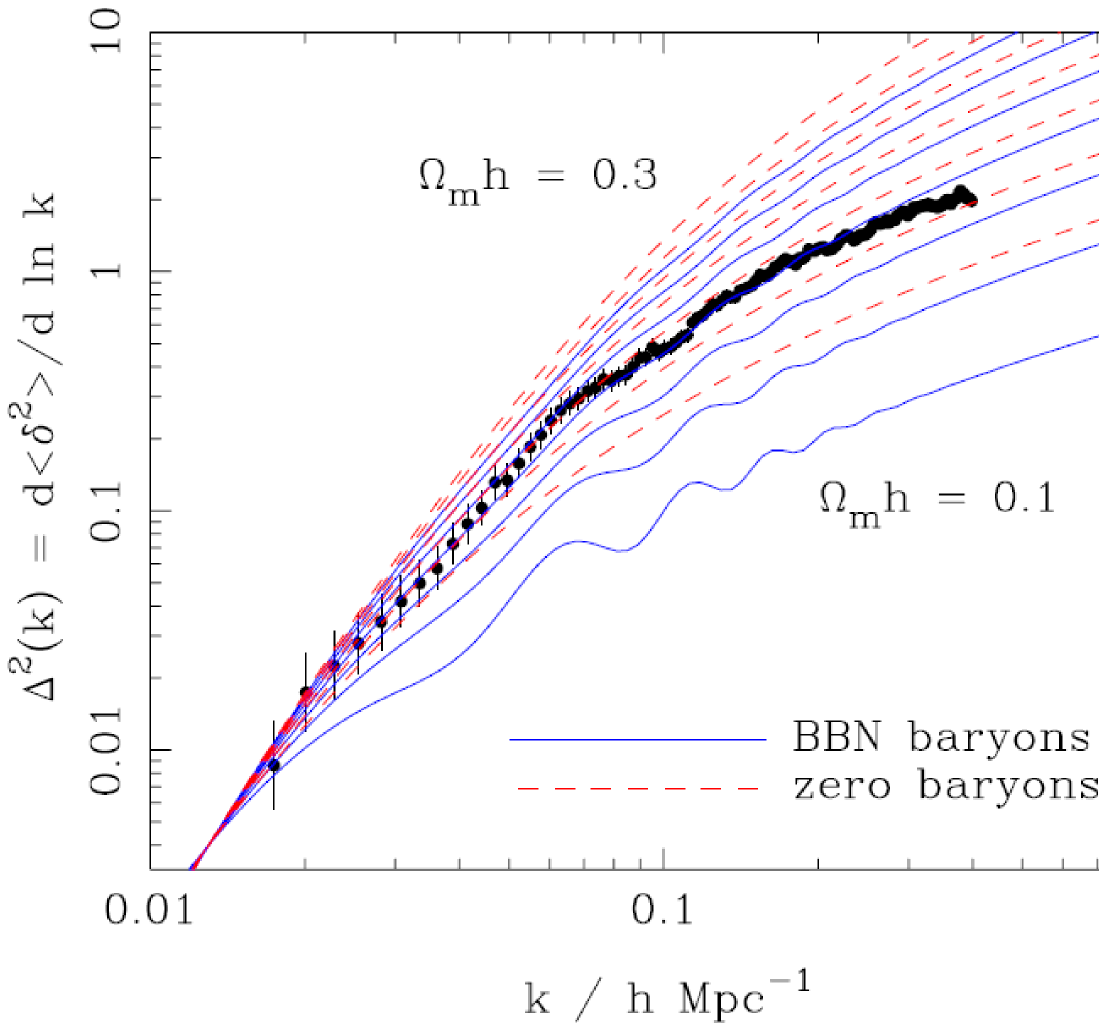
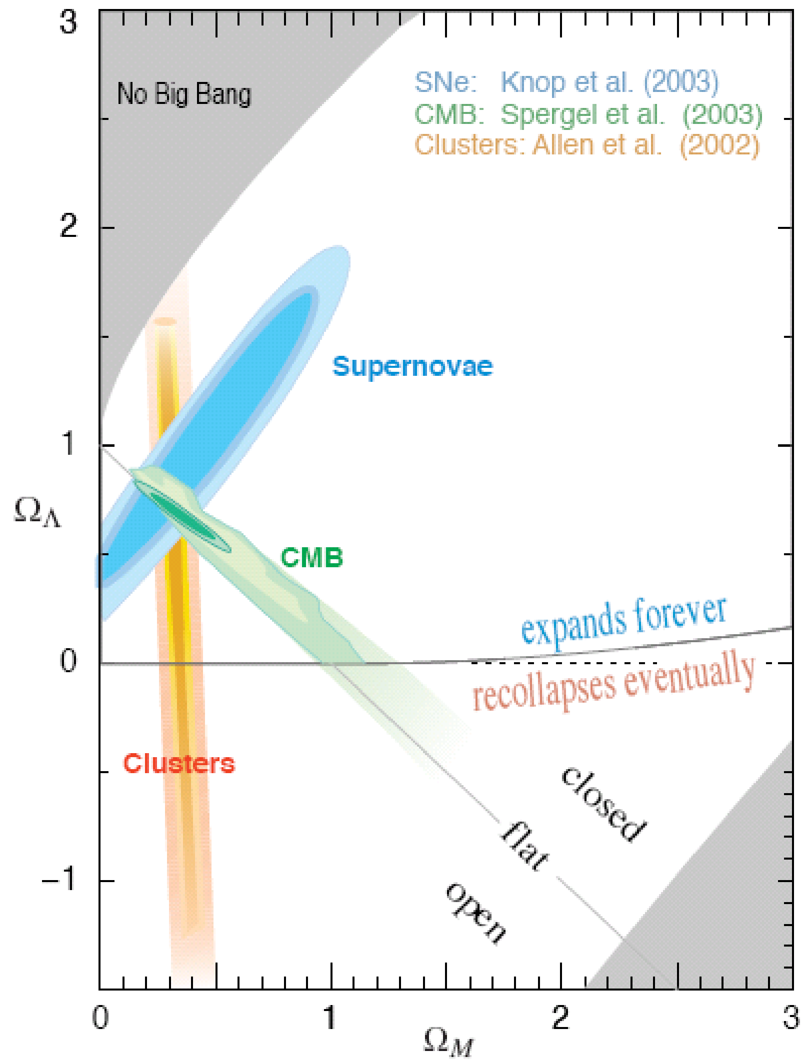


Figure 19.5: The galaxy power spectrum from the 2dFGRS, shown in dimensionless form, $\Delta^2(k) \propto k^3 P(k)$. The solid points with error bars show the power estimate. The window function correlates the results at different k values, and also distorts the large-scale shape of the power spectrum An approximate correction for the latter effect has been applied. The solid and dashed lines show various CDM models, all assuming $n = 1$. For the case with non-negligible baryon content, a big-bang nucleosynthesis value of $\Omega_b h^2 = 0.02$ is assumed, together with $h = 0.7$. A good fit is clearly obtained for $\Omega_m h \simeq 0.2$.

Combined Results

Hubble ST + WMAP + clusters

point to the existence of DM and DE:



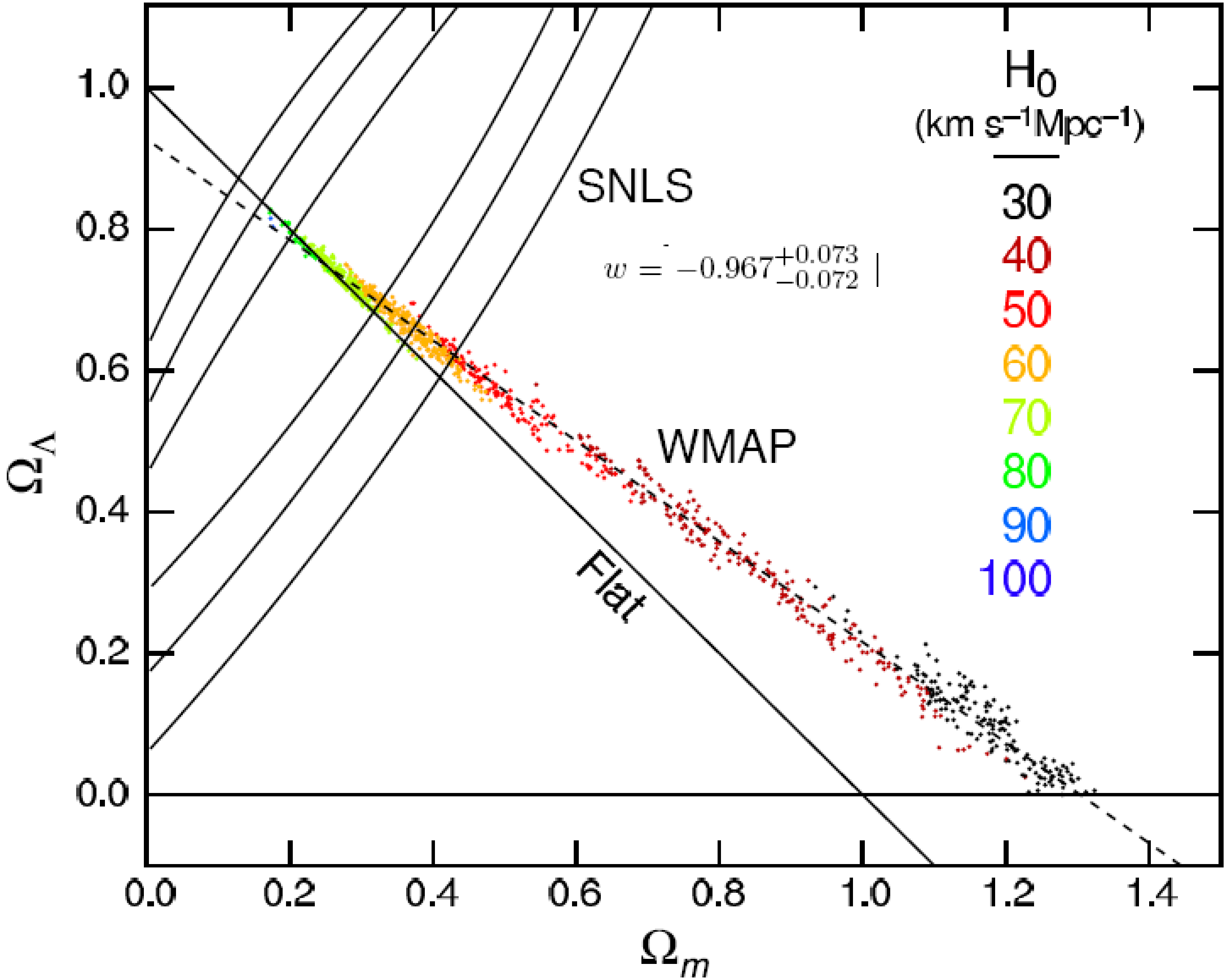
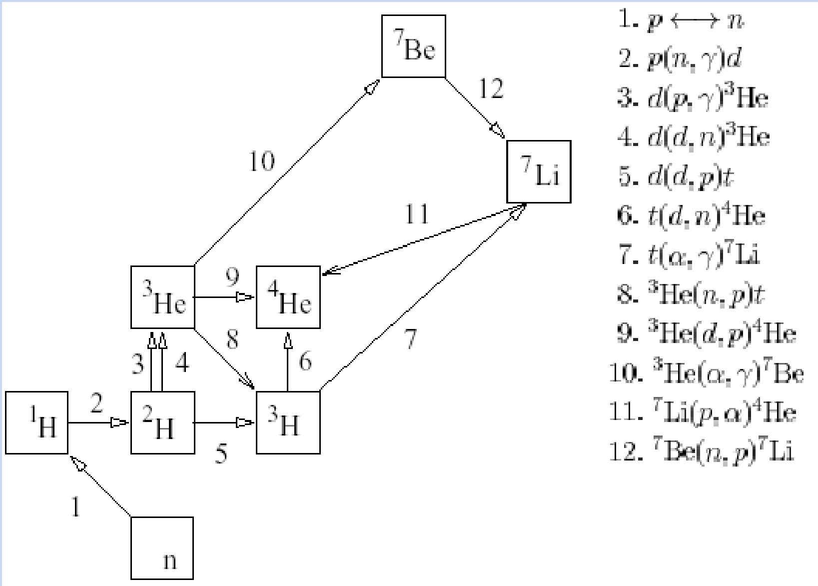
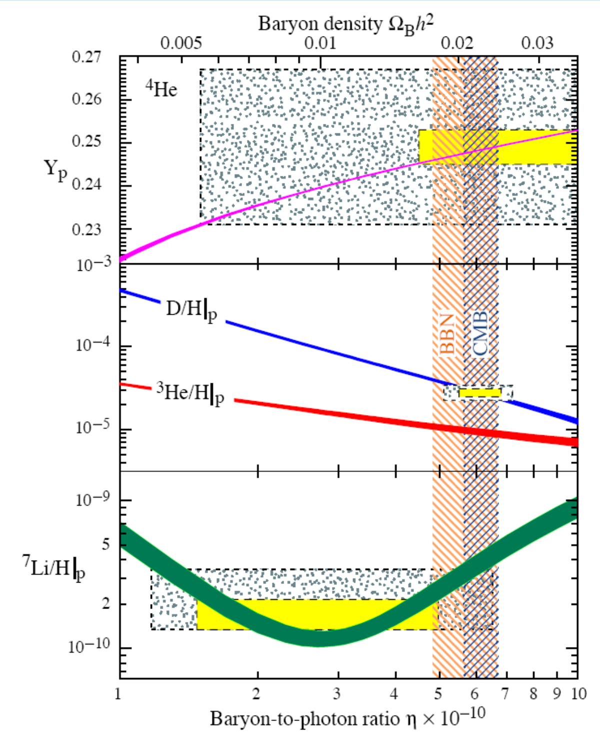


Figure 19.2: Likelihood-based probability densities on the plane Ω_Λ (*i.e.*, Ω_v assuming $w = -1$) vs Ω_m. The colored Monte-Carlo points derive from WMAP [22] and show that the CMB alone requires a flat universe $\Omega_v + \Omega_m \simeq 1$ if the Hubble

BBN constraints





$$4.7 \le \eta_{10} \le 6.5 \text{ (95\% CL)}$$

$$0.017 \le \Omega_B h^2 \le 0.024 \text{ (95\% CL)}$$

$\Omega_B \ll 1$, i.e., baryons cannot close the universe

most baryons are optically dark, probably

BBN+CMB: $4.9 < \eta_{10} < 7.1$ and $1.8 < N_\nu < 4.5$

$$5.66 < \eta_{10} < 6.58 \ (\Omega_B h^2 = 0.0226 \pm 0.0017) \text{ and } N_\nu = 3.24 \pm 1.2 \text{ at } 95\%$$

Dark Matter Candidates

Baryonic

MACHOS MAssive Compact Halo Objects

If a star's mass is less than one twentieth of our Sun, its core is not hot enough to burn either hydrogen or deuterium, so it shines only by virtue of its gravitational contraction, not luminous enough to be directly detectable by our telescopes. Brown Dwarfs and similar objects have been nicknamed MACHOs

Supermassive Black Holes, thought to power distant quasars.

detection by gravitational lensing

Non baryonic (CDM and HDM)

WIMPs (Weakly Interacting Massive Particles) or non-baryonic matter , produced shortly after the Big Bang

neutrino - HDM

sterile neutrino with KeV masses WDM

axion - CDM,

neutralino, gravitino, axino

Modified gravity models able to explain the dynamics of the LSS without DM but have problems at Solar system scales.

The role of flavor neutrino

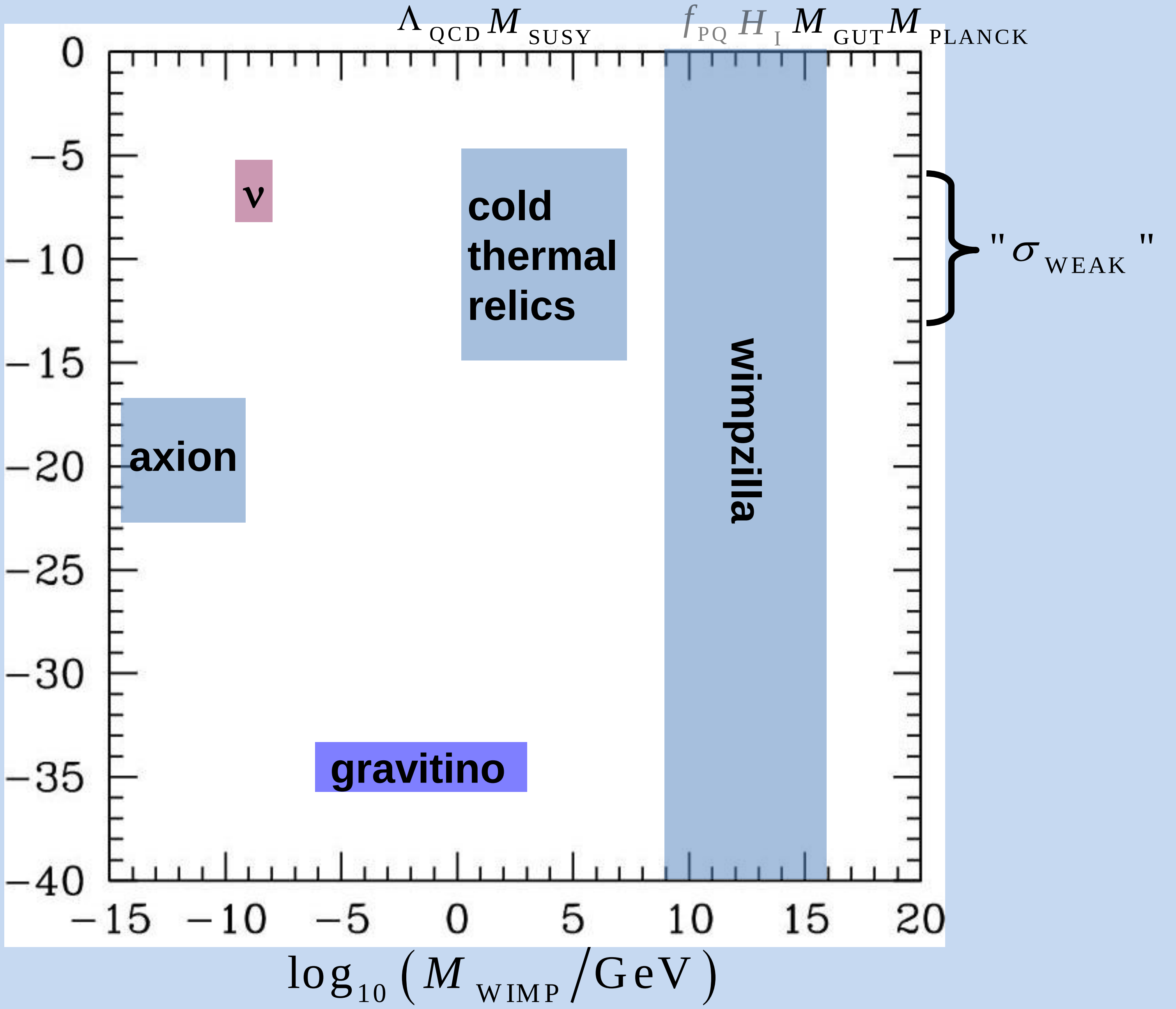
There exist robust experimental and observational evidence for the existence of neutrino oscillations, pointing to at least 2 non-zero neutrino masses.

Contribution of neutrinos to total energy density today (3 degenerate masses)

$$\Omega_\nu = \frac{3m_0}{93.14h^2 \ \mathrm{eV}^2} \qquad n_\nu = 339.3 \ \mathrm{cm}^{-3}$$

In case neutrino masses are in the eV range they can constitute several % of the DM, they can influence matter clustering (suppressing small-scale power of the matter power spectrum) providing better correspondence between models and observational data (from SDSS, cluster abundance, weak lensing, Lyman Alpha forest, CMB). *Tegmark et al., 2004*

Particle Dark Matter Candidates



Other Scales:

M_{EWK}

$M_{STERILE}$

M_{STRING}

$M_{TECHNICOLOR}$

$M_{EXTRA\ DIMENSIONS}$

DARK ENERGY

Accelerated Expansion

LSS $\Omega_M = 0.3$

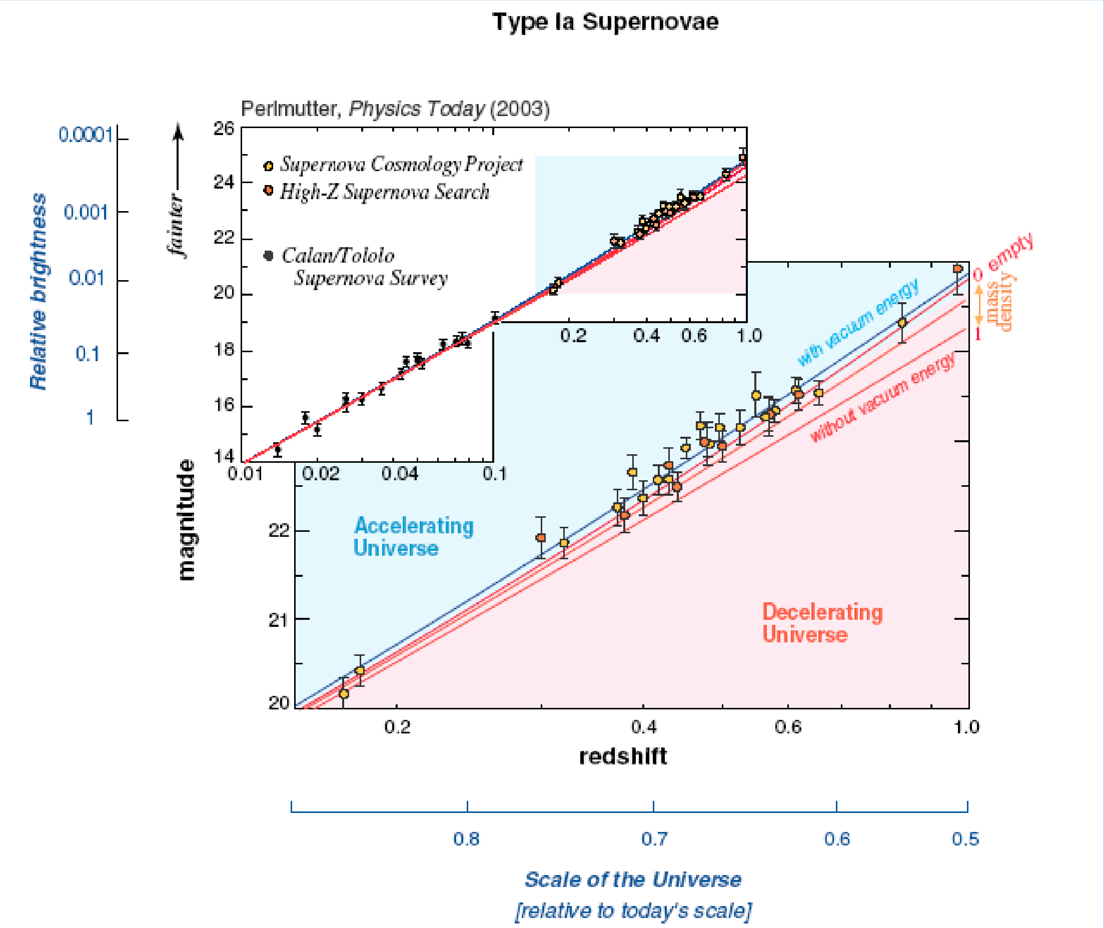
Flatness

$\Omega_0 = 1$
$\Omega_M = 0.3$
$1 - 0.3 = 0.7$

DE density $\rho \propto 10^{-30}\ \mathrm{g\ cm^{-3}}$

E. Колб: ***The unbearable lightness of nothing!***
Непоносимата лекота на нищото!

Dark Energy



SN I data about accelerated expansion.

The source of this acceleration is not understood yet. It is nicknamed dark energy.

Whatever it is, it appears to make up most of the mass of the universe – around 70%

CMB prefers "cosmological constant", not "quintessence ".

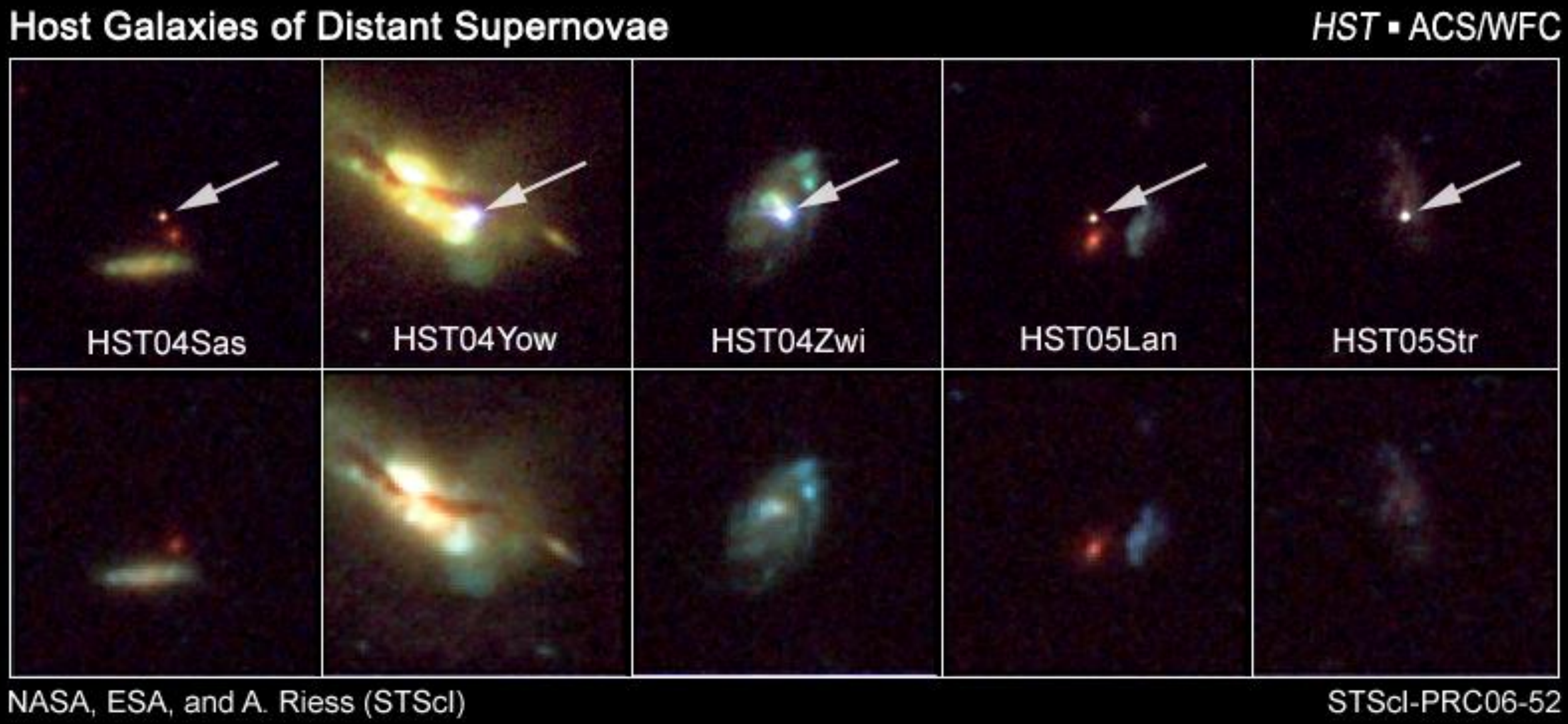
Most of the universe is made of some mysterious form of energy whose nature is completely unknown…..

Supernovas Classification

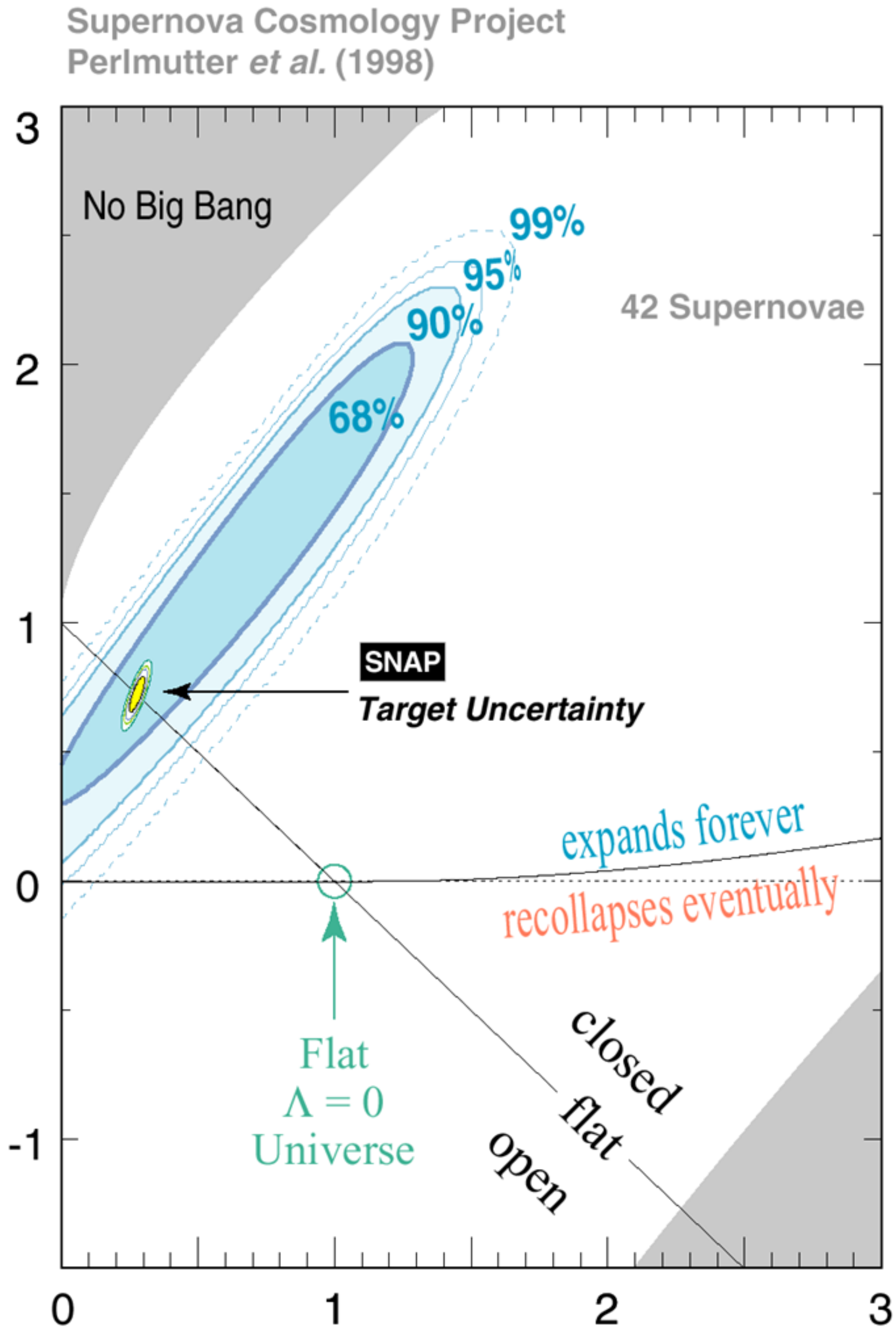
Properties	Type I	Type II
Origin	Binary system with one star a white dwarf	Massive star at end of life
Ejected mass (in $M_\odot$)	≈ 1	≈ 5
Velocity of ejected mass	10000 (km/s)	5000 (km/s)
Total kinetic energy	$\approx 10^{44}$ J	$\approx 10^{44}$ J
Radiated energy in visible light	$\approx$ few $\times 10^{42}$ J	$\approx 10^{42}$ J
Spectra	No hydrogen lines	Hydrogen lines
Corpse	None?	Neutron star
Frequency	1 in 69 years	1 in 40 years

HST, SN and DE

Hubble observations show for the first time that dark energy has been a present force for most of the universe's history.



Snapshots, taken by NASA's Hubble Space Telescope, reveal five supernovae and their host galaxies. The supernovae exploded between 3.5 and 10 billion years ago. Astronomers used the supernovae to measure the expansion rate of the universe and determine how the expansion rate is affected by the repulsive push of dark energy. Supernovae provide reliable measurements because their intrinsic brightness is well understood. They are therefore reliable distance markers.



Обичайното вещество гравитира.

Антигравитация изисква наличие на необичайна среда с P < 0 и

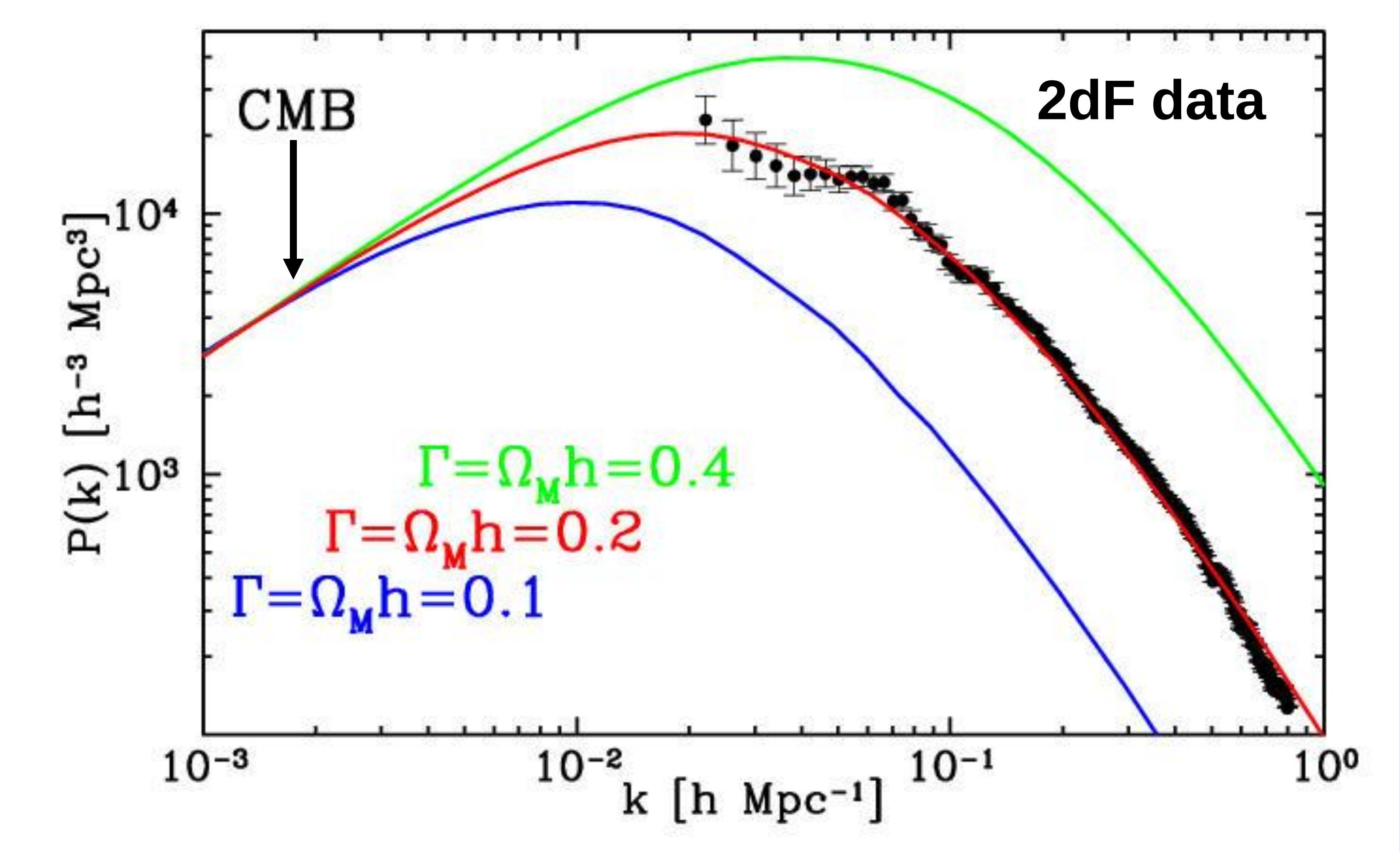
$p/\square = \omega < -1/3$ разширение с ускорение

Каква е причината за ускорението?

- космологична константа
- ненулева енергия на вакуума
- систематични ефекти
- ....

$$\Gamma \propto \Omega_M h \propto 0.25 \pm 0.05$$

$\Omega_M h$	Ω_M	h
0.25	1	0.25
0.25	0.35	0.70



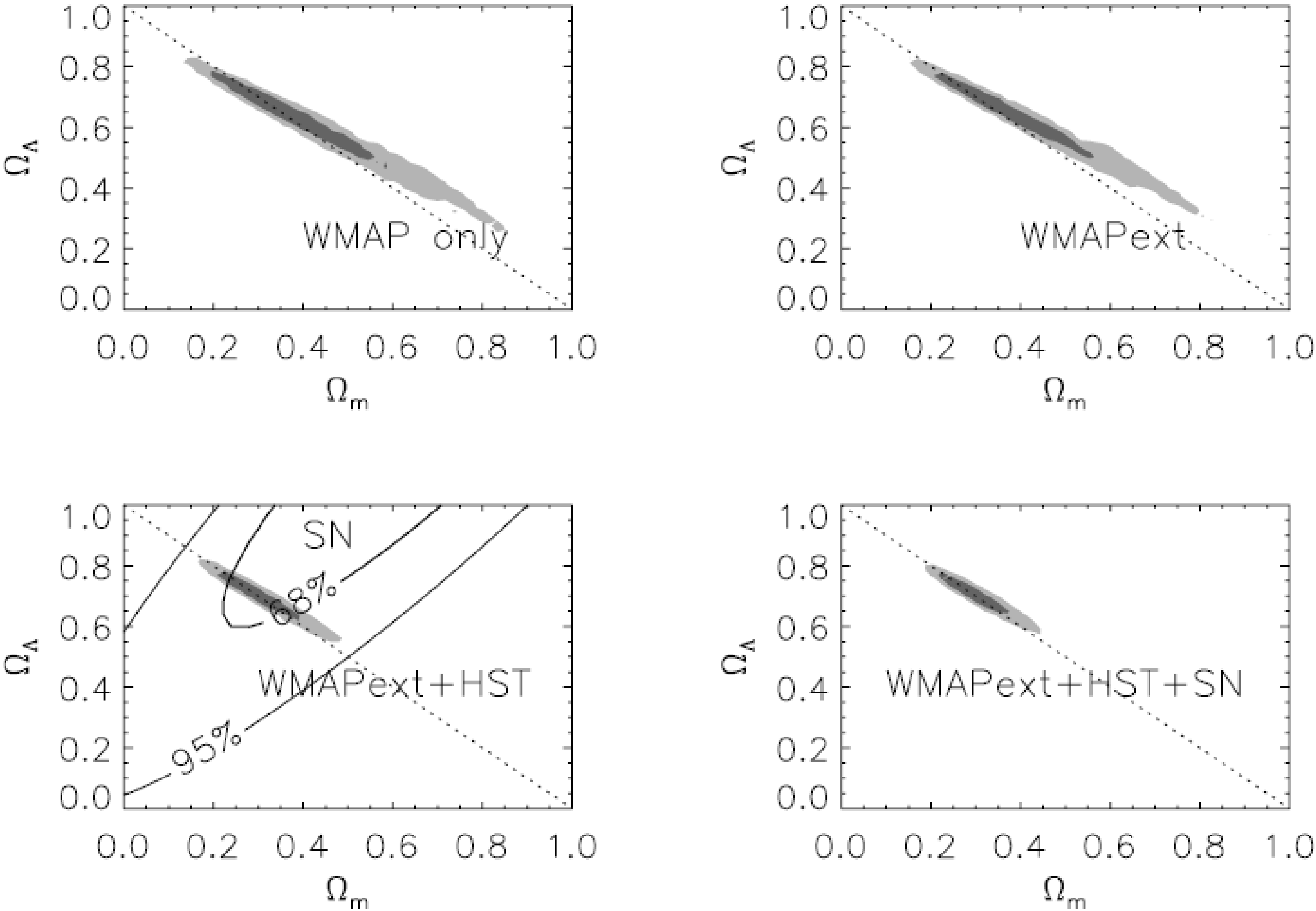
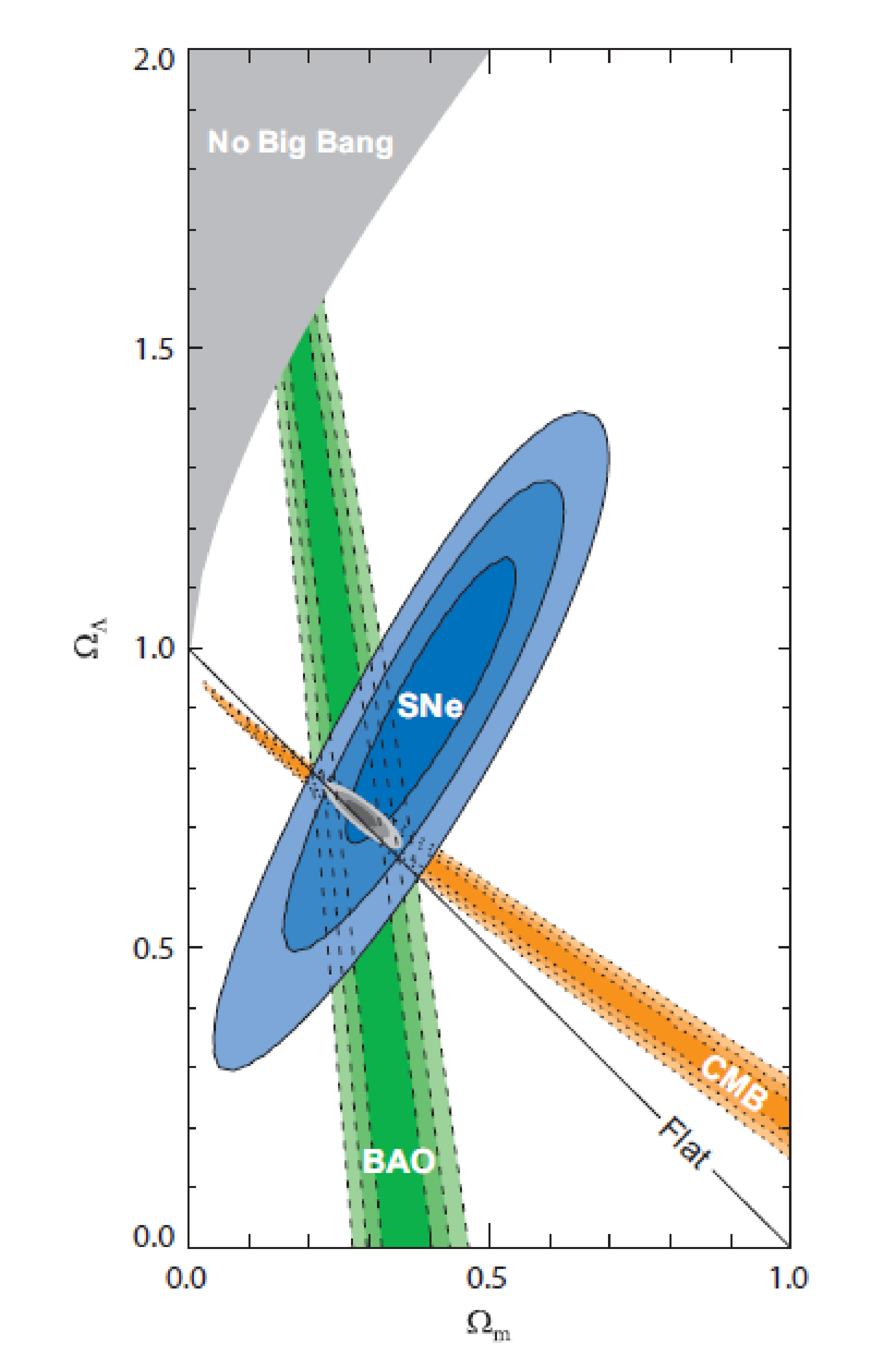


Figure 19.2: Likelihood-based confidence contours [28] over the plane Ω_Λ (*i.e.* Ω_v assuming $w = -1$) vs Ω_m. The SNe Ia results very nearly constrain $\Omega_v - \Omega_m$, whereas the results of CMB anisotropies (from the first-year WMAP data) favor a flat model with $\Omega_v + \Omega_m \simeq 1$. The intersection of these constraints is the most direct



Combined results
of studies of the dynamics,
CMB and structures of the Universe
point to the existance of DE and DM:

Union 300 SN Ia

&

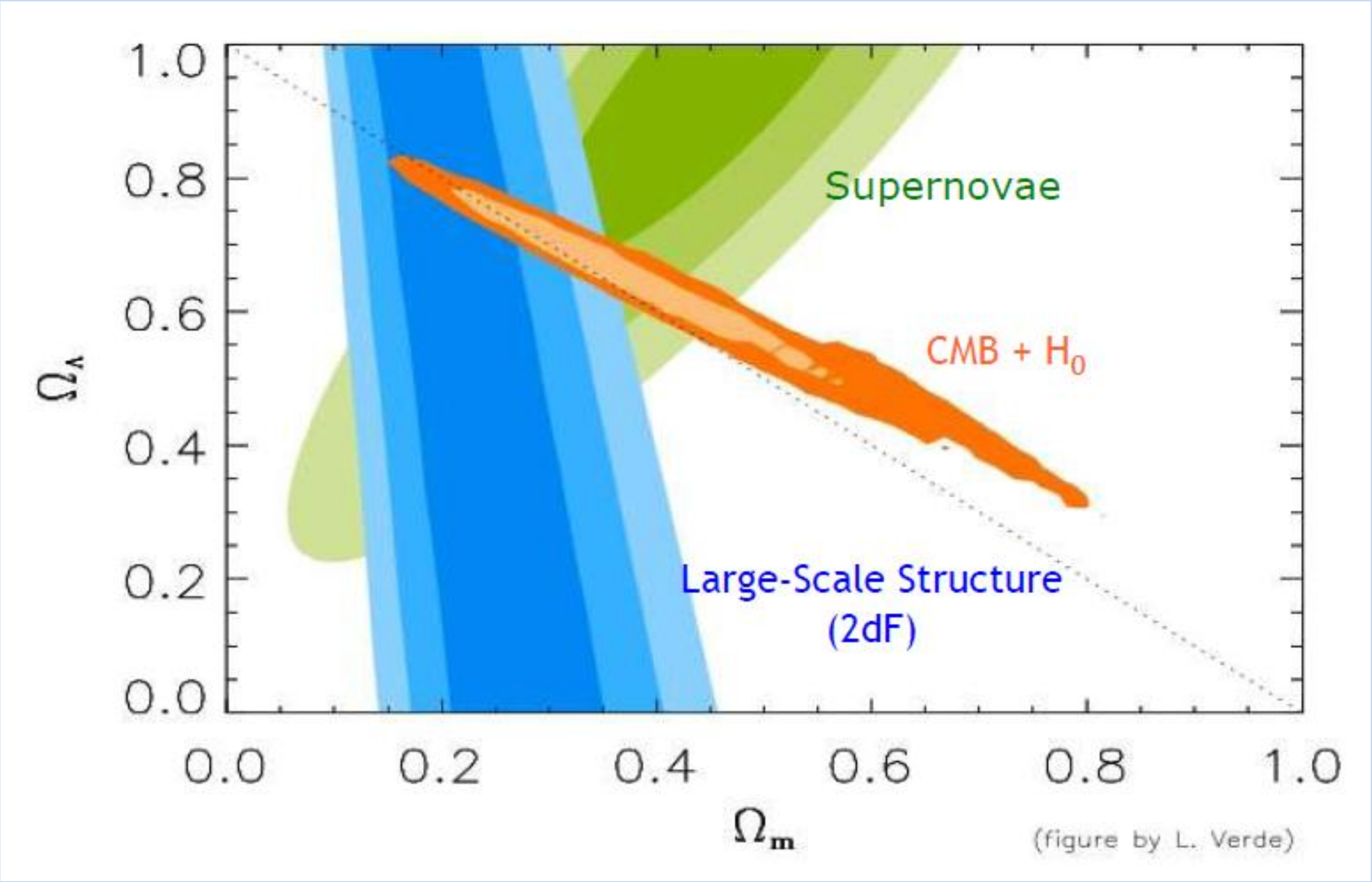
CMB

&

BAO

Agreement between independent data

$\Omega_M \sim 0.3, \ \ \Omega_\Lambda \sim 0.7$



Nature of Dark Energy

$$H^2 \equiv \left(\frac{\dot{R}}{R}\right)^2 = \frac{8\pi\, G_N\, \rho}{3} - \frac{k}{R^2} + \frac{\Lambda}{3} \,,$$

$$\frac{\ddot{R}}{R} = \frac{\Lambda}{3} - \frac{4\pi G_N}{3}\,(\rho + 3p) \,,$$

✓ **cosmological constant** $R(t) \propto e^{\sqrt{\Lambda/3}\,t}$

✓ **an energy of empty space**

Why space should contain the observed amount of energy and not, say, much mor

$$\rho_{vac} = E_{Pl}/L_{Pl}^{\;3} = 10^{120}\, \rho_{vac}^{(obs)}$$

✓ **quintessence** (time varying cosmological constant)

Unlike the energy of space envisioned by Einstein, quintessence would have the property that it could vary from place to place and moment to moment. Existing evidence tends to disfavor quintessence**.**

✓ **Accelerating universe signals a new aspect of the law of gravity**.

✓ **An effect of extra dimensions of space**

One of the extra dimensions (predicted by supersymmetry of space can mimic the effect of a dark energy by causing the expansion of our three-dimensional space to accelerate.

Summary of the 68% limits on dark energy properties from *WMAP* combined with other data sets

Section	Curvature	Parameter	+BAO+H_0	+BAO+H_0+$D_{\Delta t}$[a]	+BAO+SN[b]
Section 5.1	$\Omega_k = 0$	Constant w	-1.10 ± 0.14	-1.08 ± 0.13	-0.980 ± 0.053
Section 5.2	$\Omega_k \neq 0$	Constant w	-1.44 ± 0.27	-1.39 ± 0.25	$-0.999^{+0.057}_{-0.056}$
		Ω_k	$-0.0125^{+0.0064}_{-0.0067}$	$-0.0111^{+0.0060}_{-0.0063}$	$-0.0057^{+0.0067}_{-0.0068}$
			+H_0+SN	+BAO+H_0+SN	+BAO+H_0+$D_{\Delta t}$+SN
Section 5.3	$\Omega_k = 0$	w_0	-0.83 ± 0.16	-0.93 ± 0.13	-0.93 ± 0.12
		w_a	$-0.80^{+0.84}_{-0.83}$	$-0.41^{+0.72}_{-0.71}$	$-0.38^{+0.66}_{-0.65}$

[a] "$D_{\Delta t}$" denotes the time-delay distance to the lens system B1608+656 at $z = 0.63$ measured by Suyu et al. (2009a). See Section 3.2.5 for details.

[b] "SN" denotes the "Constitution" sample of Type Ia supernovae compiled by Hicken et al. (2009b), which is an extension of the "Union" sample (Kowalski et al. 2008) that we used for the 5-year "*WMAP*+BAO+SN" parameters presented in Komatsu et al. (2009b). Systematic errors in the supernova data are not included.

Енергия на вакуума

За енергията на вакума естественото очакване е $E_{vac} = E_{pl}$

$$\rho_{vac} = E_{vac}^{\ 4}$$

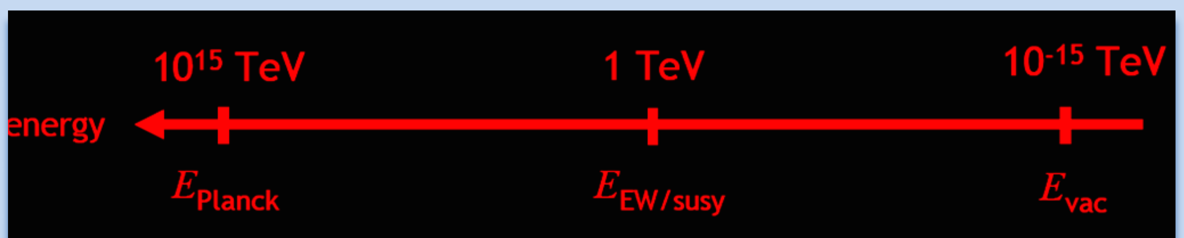
В действителност обаче $E_{vac} = 10^{-30} E_{pl}$

Newton's constant: *G = (6.67   0.01) x 10-8 cm3 g-1 sec-2*

Cosmological constant: L = (1.2   0.2) x 10-55 cm-2

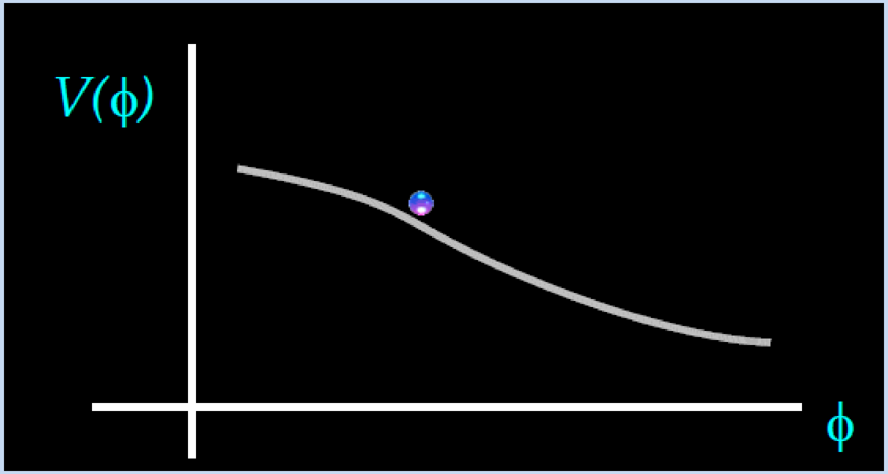
Equivalently (*ħ = c = 1),*

EPlanck = 1018 GeV , Evac = 10-12 GeV .



Причината за това силно отличие е неизвестна: мулти Вселени с различни енергии на вакуума, вечната инфлация, нова симетрия, резултат от допълнително пространствено измерение, проявяващо се при големи разст

- ТЕ е бавно меняща се динамична компонента – скаларно поле квинтесценция
- Невзаимодействащо и с прецизно фитирана маса



$$\rho_\phi = \frac{1}{2}\dot{\phi}^2 + V(\phi)$$

Енергия на вакуума

$$E_{vac} = \frac{1}{2}\sum_{bosons} \hbar w_{bosons} - \frac{1}{2}\sum_{fermions} \hbar w_{fermions}$$

w честота

$\frac{E_{vac}}{V} \propto \Lambda^4$ водещ принос

Λ ултравиолетов cut off

$$\Lambda_{QG} \propto m_{Planck} = 10^{19} Gev$$

$$\Lambda_{SUSY} > 1000 Gev$$

$$\Lambda_{EW} \propto m_Z = 100 Gev$$

$$\Lambda_{DE} = \left(\frac{3H^2}{8\pi G}\right)^{1/4} \propto 10^{-35} m_{Planck} \propto 10^{-18} m_Z$$

Astrophysical observations are pointing out huge amounts of dark matter and dark energy needed to explain the observed large scale structures and cosmic accelerating expansion. Up to now, no experimental evidence has been found, at fundamental level, to explain such mysterious components. The problem could be completely reversed considering dark matter and dark energy as shortcomings of General Relativity and claiming for the correct theory of gravity as that derived by matching the largest number of observational data. As a result, accelerating behavior of cosmic fluid and rotation curves of spiral galaxies are reproduced by means of curvature effects.

Recent supernovae of type Ia measurements and other astronomical observations suggest that our universe is in accelerating phase of evolution at the present epoch. While a dark energy of unknown form is usually proposed as the most feasible mechanism for the acceleration, there are appears some alternative conception that some effects arising from generalization of Einstein equation can mimic dark energy through a modified Friedmann equation. In this work we investigate some observational constraints

Is Cosmic Speed-Up Due to New Gravitational Physics?

Sean M. Carroll[1*], Vikram Duvvuri[1†], Mark Trodden[2‡] and Michael S. Turner[1,3,4§]
[1]*Enrico Fermi Institute, Department of Physics, and Center for Cosmological Physics, University of Chicago, 5640 S. Ellis Avenue, Chicago, IL 60637-1433, USA.*
[2]*Department of Physics, Syracuse University, Syracuse, NY 13244-1130, USA.*
[3]*Department of Astronomy & Astrophysics, University of Chicago, Chicago, IL 60637-1433, USA.*
[4]*NASA/Fermilab Astrophysics Center, Fermi National Accelerator Laboratory, Batavia, IL 60510-0500, USA.*

We show that cosmic acceleration can arise due to very tiny corrections to the usual gravitational action of general relativity of the form R^n, with $n < 0$. This eliminates the need for dark energy, though it does not address the cosmological constant problem. Since a modification to the Einstein-Hilbert action of the form R^n, with $n > 0$, can lead to early-time inflation, our proposal provides a unified and purely gravitational origin for the early and late time accelerating phases of the Universe.

2. gr-qc/0702075
Title: The cosmological constant as an eigenvalue of f(R)-gravity Hamiltonian constraint
Authors: S. Capozziello, R. Garattini
Journal-ref: Class.Quant.Grav. 24 (2007) 1627-1646

3. astro-ph/0604435
Title: Gravitational lensing in fourth order gravity
Authors: S. Capozziello, V.F. Cardone, A. Troisi
Journal-ref: Phys.Rev. D73 (2006) 104019

4. astro-ph/0604431
Title: Cosmological viability of f(R)-gravity as an ideal fluid and its compatibility with a matter dominated phase
Authors: S. Capozziello, S. Nojiri, S.D. Odintsov, A. Troisi
Journal-ref: Phys.Lett. B639 (2006) 135-143

5. astro-ph/0603522:
Title: Low surface brightness galaxies rotation curves in the low energy limit of R^n gravity : no need for dark matter?
Authors: S. Capozziello, V.F. Cardone, A. Troisi
Journal-ref: Mon.Not.Roy.Astron.Soc. 375 (2007) 1423-1440

astro-ph/0607639

Dark matter and dark energy as a effects of Modified Gravity

Authors: Andrzej Borowiec, Wlodzimierz Godlowski, Marek Szydlowski

Comments: Lectures given at 42nd Karpacz Winter School of Theoretical Physics: Ladek, Poland, 6-11 Feb 2006

Journal-ref: Int.J.Geom.Meth.Mod.Phys. 4 (2007) 183-196

We explain the effect of dark matter (flat rotation curve) using modified gravitational dynamics. We investigate in this context a low energy limit of generalized general relativity with a nonlinear Lagrangian $\mathcal{L} \propto R^n$, where R is the (generalized) Ricci scalar and n is parameter estimated from SNIa data. We estimate parameter β in modified gravitational potential $V(r) \propto -\frac{1}{r}(1+(\frac{r}{r_c})^\beta)$. Then we compare value of β obtained from SNIa data with β parameter evaluated from the best fitted rotation curve. We find $\beta \simeq 0.7$ which becomes in good agreement with an observation of

only $\beta \simeq 0$ values are not in contradiction with solar system data in spite of the fact that there are a lot of speculations to fit observational data with β values significantly different from zero.

Baryonic Density

$$\Omega_b h^2 = 3.65\times10^7\eta, \quad \Omega_b = \frac{\rho_b}{\rho_c}, \quad \rho_c = \frac{3H^2}{8\pi G_N}$$

- BBN $\quad 0.017 \le \Omega_{\rm B} h^2 \le 0.024$ (95% CL)

Standard Big Bang Nucleosynthesis provides a probe of the baryonic density at the epoch when the Universe was few minutes.

- D towards low Z QAS at high z $\quad \Omega_b h^2 = 0.0216^{+0.0020}_{-0.0021}$

The recent deuterium observations in pristine enviroments towards quasars at high z D/H=(3 0.4) 10^{-5} have provided a precise determination of the baryonic density.

$$4.7\times10^{-10} < \eta < 6.5\times10^{-10}$$

- CMB

Precise determination, corresponding to the epoch, when the Universe was several hundred thousands years old z ~ 1000, from observations of the anisotropy of the CMB by DASI, BOOMERANG, MAXIMA and WMAP experiments .

$$\Omega_b h^2 = 0.0223 \pm 0.0007$$

$$\eta = 6.11 \pm 0.19$$

Baryonic density is ~ 0.045 of the total, i.e. much bigger than the visible matter (0.005), considerably smaller than the density of clustered matter (0.3).

Why the baryonic component is negligible constituent of the total density ?

Antimatter in the Universe

Missions for search of cosmic/galactic antimatter: PAMELA, BESS, AMS, AMS 2 (2009), PEBS(2010), etc

- The cosmic ray results from search of antiprotons, positrons and antinuclei indicate that there is not significant quantity of antimatter objects within a radius 1 Mpc.

BESS 98 $\bar{H}e/He < 1.7.10^{-6}$

AMS 01 $\bar{H}e/He < 1.1.10^{-6}$

$$\bar{p}/p \sim 10^{-5} \text{ at } E < 2 \text{ GeV}$$
$$\bar{p}/p \sim 10^{-4} \text{ at } E > 2 \text{ GeV}$$

PAMELA antiprotons secondary origin, positron excess ?

HESS positron excess

- Gama ray flux measurements exclude significant amounts of antimatter

up to the distance of galaxy cluster scales ~ 10 -20 Mpc.

Steigman 79, Stecker 85, Dolgov 99

CR and gama ray data do not rule out antimatter domains > 10 -20 Mpc,

or small ratios of antimatter/matter objects on small scales (stars, globular clusters).

Subdominant domains of antimatter allowed within the Galaxy as well.

Both theory and observations allow astronomically significant antimatter .

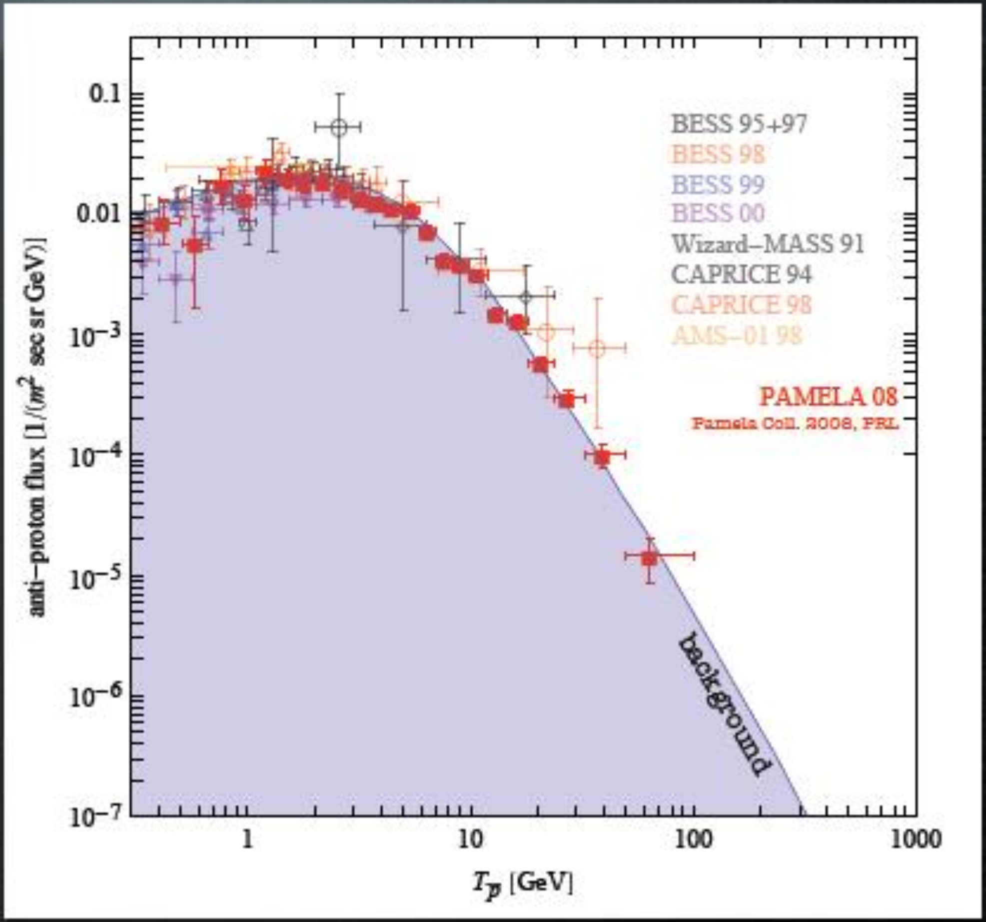
Baryon Asymmetry generation?

Models of separation of matter from antimatter domains ?

Data sets

Antiprotons from PAMELA:

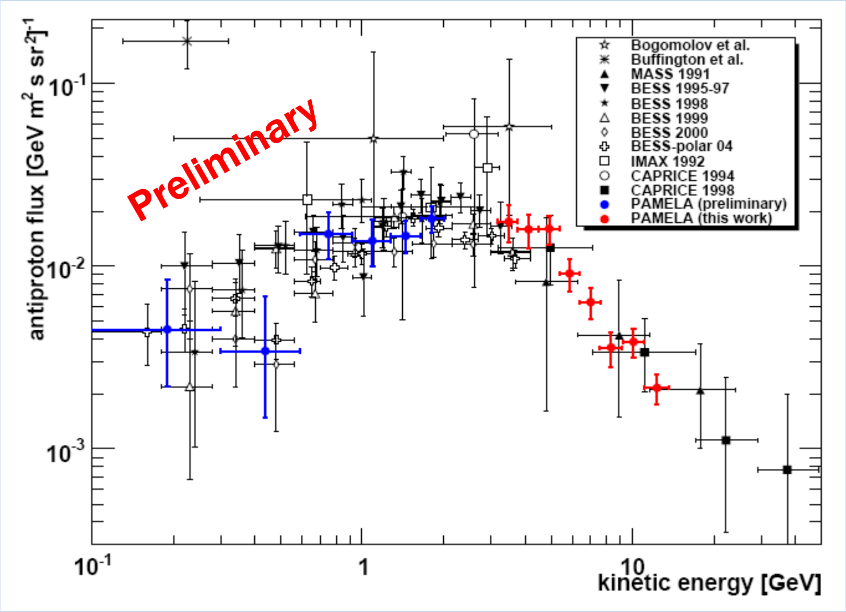
- consistent with the background

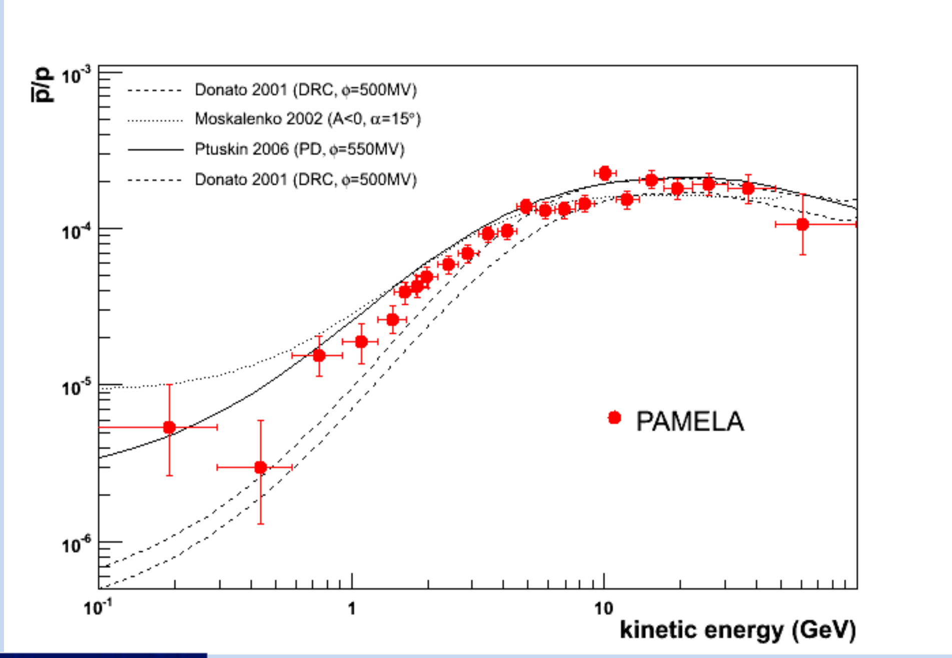


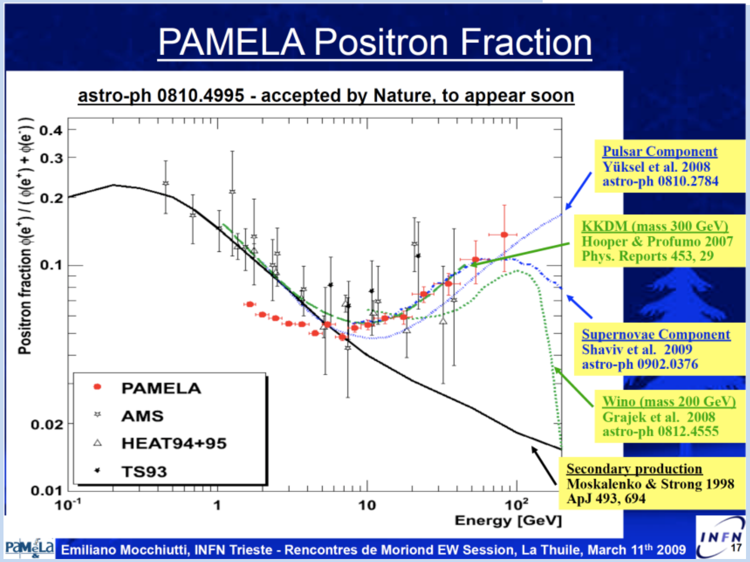
(about 1000 $\bar{p}$ collected)

Results from PAMELA -2

Emiliano Mocchiutti







Evidence for Dark Matter Annihilation?

Matter Content in the Universe

To solve the Friedmann equations, one has to specify the Universe matter content and the equation of state for each of the constituents. Current observations point to at least four components:

$\Omega_{\rm r} = 2.47 \times 10^{-5} h^{-2}$

$\Omega_\nu h^2 \leq 0.0076 \quad 95\%\ \mathrm{CL}$

Radiation (relativistic degrees of freedom) ~0.002%

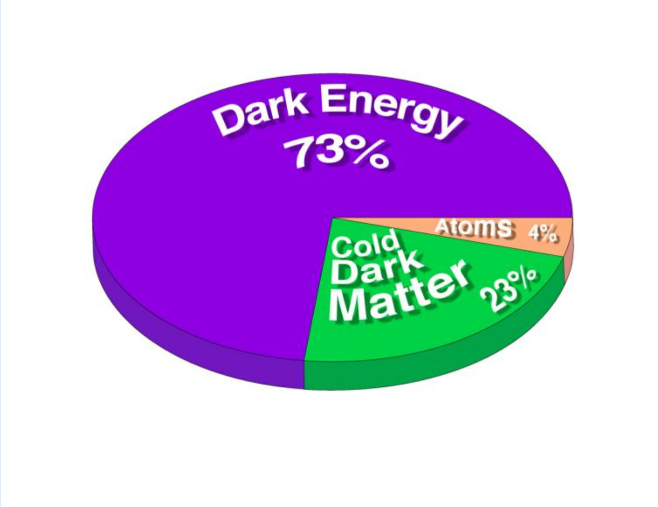
Today this component consists of the photons and neutrino and gives negligible contribution into total energy density. However, it was a major fraction at early times.

Baryonic matter ~4% $\Omega_{\rm b} h^2 = 0.022 \pm 0.001$

Dark matter ~20% $\Omega_{\rm nbm} h^2 = 0.106 \pm 0.008$

Was not directly detected yet, but should be there.

Constitutes major matter fraction today.

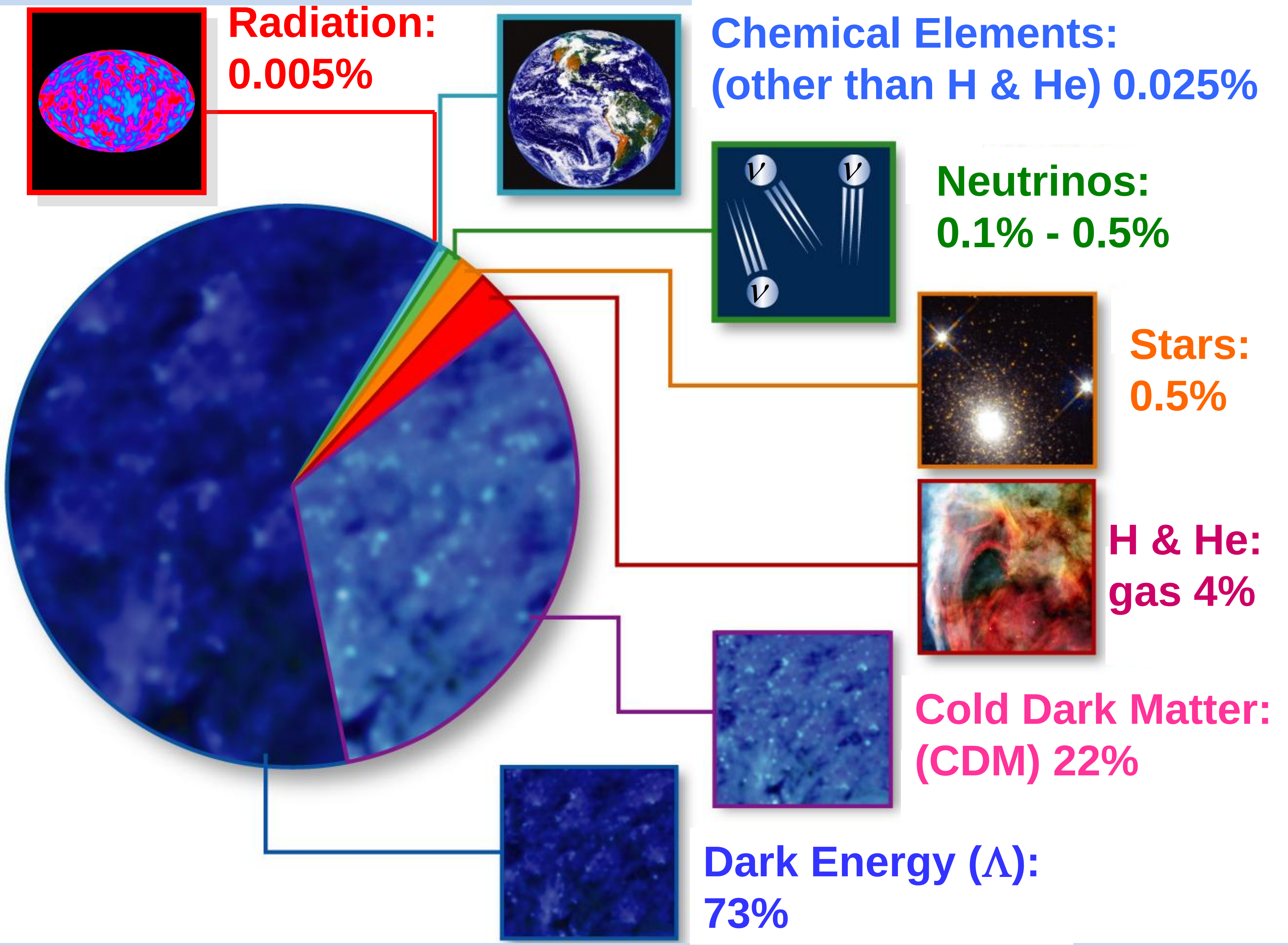


Dark energy ~76%

It provides the major fraction of the total energy density.

Was not anticipated and appears as the biggest surprise and challenge for particle physics, though conceptually it can be very simple, being just a `cosmological constant' or vacuum energy. $\Omega_m + \Omega_v = 1.011 \pm 0.012$

- 4% - H+He, 0.0025% heavy elements, 0.8% stars, 0.005% CMB
- 23% - DM, 73% DE, 0.17% neutrino



Radiation: 0.005%
Chemical Elements: (other than H & He) 0.025%
Neutrinos: 0.1% - 0.5%
ν
ν
ν
Stars: 0.5%
H & He: gas 4%
Cold Dark Matter: (CDM) 22%
Dark Energy (Λ): 73%

Cosmological Parameters

	WMAP5 alone	WMAP5 + BAO + SN
$\Omega_b h^2$	0.0227 ± 0.0006	0.0227 ± 0.0006
$\Omega_{cdm} h^2$	0.110 ± 0.006	0.113 ± 0.003
Ω_Λ	0.74 ± 0.03	0.726 ± 0.015
n	$0.963^{+0.014}_{-0.015}$	0.960 ± 0.013
τ	0.087 ± 0.017	0.084 ± 0.016
$\Delta^2_{\mathcal{R}} \times 10^9$	2.41 ± 0.11	2.44 ± 0.10
h	0.72 ± 0.03	0.705 ± 0.013
σ_8	0.80 ± 0.04	0.81 ± 0.03
$\Omega_m h^2$	0.133 ± 0.006	0.136 ± 0.004

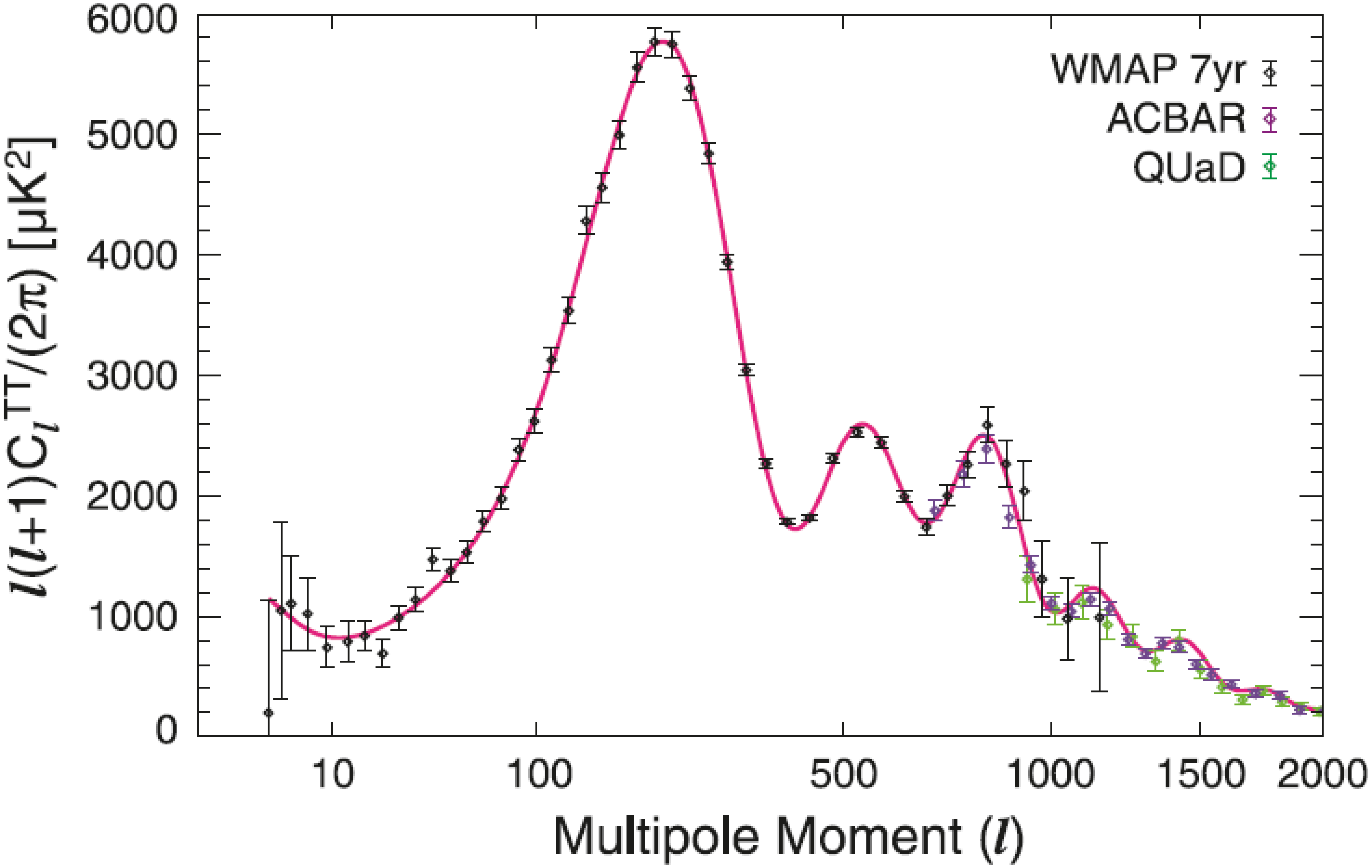


FIG. 7.— The *WMAP* 7-year temperature power spectrum (Larson et al. 2010), along with the temperature power spectra from the ACBAR (Reichardt et al. 2009) and QUaD (Brown et al. 2009) experiments. We show the ACBAR and QUaD data only at $l \geq 690$, where the errors in the *WMAP* power spectrum are dominated by noise. We do not use the power spectrum at $l > 2000$ because of a potential contribution from the SZ effect and point sources. The solid line shows the best-fitting 6-parameter flat ΛCDM model to the *WMAP* data alone (see the 3rd column of Table 1 for the maximum likelihood parameters).

Class	Parameter	*WMAP* 7-year ML[a]	*WMAP*+BAO+H_0 ML	*WMAP* 7-year Mean[b]	*WMAP*+BAO+H_0 Mean
Primary	$100\Omega_b h^2$	2.270	2.246	$2.258^{+0.057}_{-0.056}$	2.260 ± 0.053
	$\Omega_c h^2$	0.1107	0.1120	0.1109 ± 0.0056	0.1123 ± 0.0035
	Ω_Λ	0.738	0.728	0.734 ± 0.029	$0.728^{+0.015}_{-0.016}$
	n_s	0.969	0.961	0.963 ± 0.014	0.963 ± 0.012
	τ	0.086	0.087	0.088 ± 0.015	0.087 ± 0.014
	$\Delta^2_{\mathcal{R}}(k_0)$[c]	2.38×10^{-9}	2.45×10^{-9}	$(2.43 \pm 0.11) \times 10^{-9}$	$(2.441^{+0.088}_{-0.092}) \times 10^{-9}$
Derived	σ_8	0.803	0.807	0.801 ± 0.030	0.809 ± 0.024
	H_0	71.4 km/s/Mpc	70.2 km/s/Mpc	71.0 ± 2.5 km/s/Mpc	$70.4^{+1.3}_{-1.4}$ km/s/Mpc
	Ω_b	0.0445	0.0455	0.0449 ± 0.0028	0.0456 ± 0.0016
	Ω_c	0.217	0.227	0.222 ± 0.026	0.227 ± 0.014
	$\Omega_m h^2$	0.1334	0.1344	$0.1334^{+0.0056}_{-0.0055}$	0.1349 ± 0.0036
	$z_{\rm reion}$[d]	10.3	10.5	10.5 ± 1.2	10.4 ± 1.2
	t_0[e]	13.71 Gyr	13.78 Gyr	13.75 ± 0.13 Gyr	13.75 ± 0.11 Gyr

[a]Larson et al. (2010). "ML" refers to the Maximum Likelihood parameters.

[b]Larson et al. (2010). "Mean" refers to the mean of the posterior distribution of each parameter. The quoted errors show the 68% confidence levels (CL).

[c]$\Delta^2_{\mathcal{R}}(k) = k^3 P_{\mathcal{R}}(k)/(2\pi^2)$ and $k_0 = 0.002$ Mpc^{-1}.

[d]"Redshift of reionization," if the universe was reionized instantaneously from the neutral state to the fully ionized state at $z_{\rm reion}$. Note that these values are somewhat different from those in Table 1 of Komatsu et al. (2009b), largely because of the changes in the treatment of reionization history in the Boltzmann code CAMB (Lewis 2008).

[e]The present-day age of the universe.

Summary of the 95% confidence limits on deviations from the simple (flat, Gaussian, adiabatic, power-law) ΛCDM model except for dark energy parameters

Sec.	Name	Case	*WMAP* 7-year	*WMAP*+BAO+SN[a]	*WMAP*+BAO+H_0
§ 4.1	Grav. Wave[b]	No Running Ind.	$r < 0.36$[c]	$r < 0.20$	$r < 0.24$
§ 4.2	Running Index	No Grav. Wave	$-0.084 < dn_s/d\ln k < 0.020$[c]	$-0.065 < dn_s/d\ln k < 0.010$	$-0.061 < dn_s/d\ln k < 0.017$
§ 4.3	Curvature	$w = -1$	N/A	$-0.0178 < \Omega_k < 0.0063$	$-0.0133 < \Omega_k < 0.0084$
§ 4.4	Adiabaticity	Axion	$\alpha_0 < 0.13$[c]	$\alpha_0 < 0.064$	$\alpha_0 < 0.077$
		Curvaton	$\alpha_{-1} < 0.011$[c]	$\alpha_{-1} < 0.0037$	$\alpha_{-1} < 0.0047$
§ 4.5	Parity Violation	Chern-Simons[d]	$-5.0^\circ < \Delta\alpha < 2.8^\circ$[e]	N/A	N/A
§ 4.6	Neutrino Mass[f]	$w = -1$	$\sum m_\nu < 1.3$ eV[c]	$\sum m_\nu < 0.71$ eV	$\sum m_\nu < 0.58$ eV[g]
		$w \neq -1$	$\sum m_\nu < 1.4$ eV[c]	$\sum m_\nu < 0.91$ eV	$\sum m_\nu < 1.3$ eV[h]
§ 4.7	Relativistic Species	$w = -1$	$N_{\rm eff} > 2.7$[c]	N/A	$4.34^{+0.86}_{-0.88}$ (68% CL)[i]
§ 6	Gaussianity[j]	Local	$-10 < f_{NL}^{\rm local} < 74$[k]	N/A	N/A
		Equilateral	$-214 < f_{NL}^{\rm equil} < 266$	N/A	N/A
		Orthogonal	$-410 < f_{NL}^{\rm orthog} < 6$	N/A	N/A

[a] "SN" denotes the "Constitution" sample of Type Ia supernovae compiled by Hicken et al. (2009b), which is an extension of the "Union" sample (Kowalski et al. 2008) that we used for the 5-year "*WMAP*+BAO+SN" parameters presented in Komatsu et al. (2009b). Systematic errors in the supernova data are not included. While the parameters in this column can be compared directly to the 5-year *WMAP*+BAO+SN parameters, they may not be as robust as the "*WMAP*+BAO+H_0" parameters, as the other compilations of the supernova data do not give the same answers (Hicken et al. 2009b; Kessler et al. 2009). See Section 3.2.4 for more discussion. The SN data will be used to put limits on dark energy properties. See Section 5 and Table 4.

[b] In the form of the tensor-to-scalar ratio, r, at $k = 0.002$ Mpc^{-1}.

[c] Larson et al. (2010).

[d] For an interaction of the form given by $[\phi(t)/M]F_{\alpha\beta}\tilde{F}^{\alpha\beta}$, the polarization rotation angle is $\Delta\alpha = M^{-1}\int\frac{dt}{a}\dot{\phi}$.

[e] The 68% CL limit is $\Delta\alpha = -1.1^\circ \pm 1.3^\circ$ (stat.) $\pm 1.5^\circ$ (syst.), where the first error is statistical and the second error is systematic.

[f] $\sum m_\nu = 94(\Omega_\nu h^2)$ eV.

[g] For *WMAP*+LRG+H_0, $\sum m_\nu < 0.44$ eV.

[h] For *WMAP*+LRG+H_0, $\sum m_\nu < 0.71$ eV.

[i] The 95% limit is $2.7 < N_{\rm eff} < 6.2$. For *WMAP*+LRG+H_0, $N_{\rm eff} = 4.25 \pm 0.80$ (68%) and $2.8 < N_{\rm eff} < 5.9$ (95%).

[j] V+W map masked by the *KQ75y7* mask. The Galactic foreground templates are marginalized over.

[k] When combined with the limit on $f_{NL}^{\rm local}$ from *SDSS*, $-29 < f_{NL}^{\rm local} < 70$ (Slosar et al. 2008), we find $-5 < f_{NL}^{\rm local} < 59$.

Наред с безпрецедентната точност при определяне на редица характеристики на Вселената, като например плътността на познатото ни барионно вещество, следваща от данните относно КН и КМФ, съвременната космология се сблъсква със сериозни загадки. Съгласно съвкупност от независими наблюдателни данни от свръхнови, КМФ, КН и др. 22% от пълната плътност на Вселената представлява тъмно вещество, а 73% е във вид на тъмна енергия. Каква е природата на 95% от материята на Вселената?

Дали съществува космологична константа или поле отговорни за тъмната енергия, дали нови екзотични физични теории, като суперсиметрията например, ще предложат кандидата за тъмното вещество или тъмното вещество и енергия са сигнатури за необходимост от алтернативна гравитационна теория ?

Очакваме бъдещите изследвания и в частност Големия адронен колайдер, да дадат отговори на част от космологичните загадки.

Summary

BBN is the most sensitive cosmological probe of number of neutrino species, of distortions in the energy distribution of neutrinos, lepton asymmetry, neutrino mass differences and mixings, etc. It provides constraints on many neutrino characteristics.

Active-sterile oscillations lead to additional species into equilibrium, distort neutrino spectrum and neutrino-antineutrino asymmetry, thus influencing Universe expantion, CMB and BBN.

BBN constraints on neutrino oscillations parameters depend nontrivially on the population of sterile neutrino and the lepton asymmetry in the Universe.

CMB+LSS constraints (sensitive to the total energy density can be obtained $1<\delta N_s<5$,

CMB +LSS constrains total neutrino mass < 0.6 eV

CMB+LSS sensitive to the total energy density , they put the most stringent constraints to the sum of neutrino masses.

These constraints are much stronger than the existing laboratory mass constraints.

Future Planck mission will strengthen CMB constraints considerably.

Какво знаем за Вселената

еднородна и изотропна на големи мащаби

плоска, с пренебрежима кривина

разширява се с ускорение от 5 млрд години

доминирана от равномерно разпределена тъмна енергия ~ 73% с характеристики на Λ

Веществото е предимно тъмно и небарионно, плътността му е подкритична ~ 0.27 , барионната му компонента съставлява <5%!

Леките елементи деутерий, хелий-3, хелий-4 и литий-7 са синтезирани в ранната Вселена.

Днешната Вселена е изпълнена с реликтови фотони и неутрино.

Наблюдателни свидетелства от различни епохи на еволюцията на Вселената: обилието на леките елементи от първите минути на Големия Взрив, КМФ от 300 000 г-ни от началото, структурите от първите милиард години, предоставят информация за характеристиките на Вселената и поставят ограничения върху физиката отвъд СМ.

Бъдещи космични мисии и наземни наблюдения и ескперименти на ускорители и колайдери да прецизират знанията за нашата Вселената и изяснят космологичните загадки - ТВ, ТЕ, бариогенезис, инфлация, плоскостност, изотропия, ...