Towards the Origin of the Universe

H. J. de Vega

LPTHE, CNRS/Université Paris VI-P. & M. Curie

European Science Open Forum, July 5 2010,

Torino, Italia

The History of the Universe

It is a history of EXPANSION and cooling down.

EXPANSION: the space itself expands with the time.

All lengths grow as time goes on: wavelengths, distances between objects. Atoms and elementary particle sizes remain unchanged.

The expansion of the Universe started explosively fast: the Big Bang !!

The Big Bang has no center.
The Universe expands similarly at all points.

This is very different to supernova explosions, atomic bombs or firecrackers.

Universe homogeneous and isotropic till 100 Myr ago.
Cooling: temperature decreases as lenghts increase.

Inflation and subsequent eras of the Universe

Main Events	Time from beginning	Tempe-rature	Expansion factor
Inflation	10^{-36} sec	10^{29} K	10^{28}
Protons & neutrons form	10^{-5} sec	10^{12} K	10^{45}
D, He, Li form	20 sec	10^{9} K	10^{48}
Non-relativistic particles dominate	57000 yr	8000 K	3×10^{53}
Atoms form	370000 yr	3000 K	10^{54}
Galaxies and Stars start to form	80 Myr	90 K	3×10^{55}
Today	13.7 Gyr	3 K	10^{57}

Standard Cosmological Model: ΛCDM

ΛCDM = Cold Dark Matter + Cosmological Constant

- Begins by the inflationary era.
- Gravity is described by Einstein's General Relativity.
- Particle Physics described by the Standard Model of Particle Physics: $SU(3) \otimes SU(2) \otimes U(1) =$ qcd+electroweak model.
- CDM: dark matter is cold (non-relativistic) when structure formation happens.
  DM is outside the SM of particle physics.
- Dark energy described by the cosmological constant Λ.

Effective theory of inflation gives an excellent description of the observations. Predicts from present observations 10^{16} GeV $\sim 10^{29}$ K as energy scale of inflation $\Longrightarrow$ Grand unification scale in particle physics.

Standard Cosmological Model: ΛCDM

ΛCDM = Cold Dark Matter + Cosmological Constant begins by the Inflationary Era. Explains the Observations:

- Seven years WMAP data and further CMB data
- Light Elements Abundances
- Large Scale Structures (LSS) Observations. BAO.
- Acceleration of the Universe expansion: Supernova Luminosity/Distance and Radio Galaxies.
- Gravitational Lensing Observations
- Lyman α Forest Observations
- Hubble Constant (H_0) Measurements
- Properties of Clusters of Galaxies
- Measurements of the Age of the Universe

The Fossil Cosmic Microwave Background

Protons and electrons bind together forming neutral hydrogen by time $= 370000$ yr.

Since then the Universe became electrically neutral photons were free to travel across the Universe.

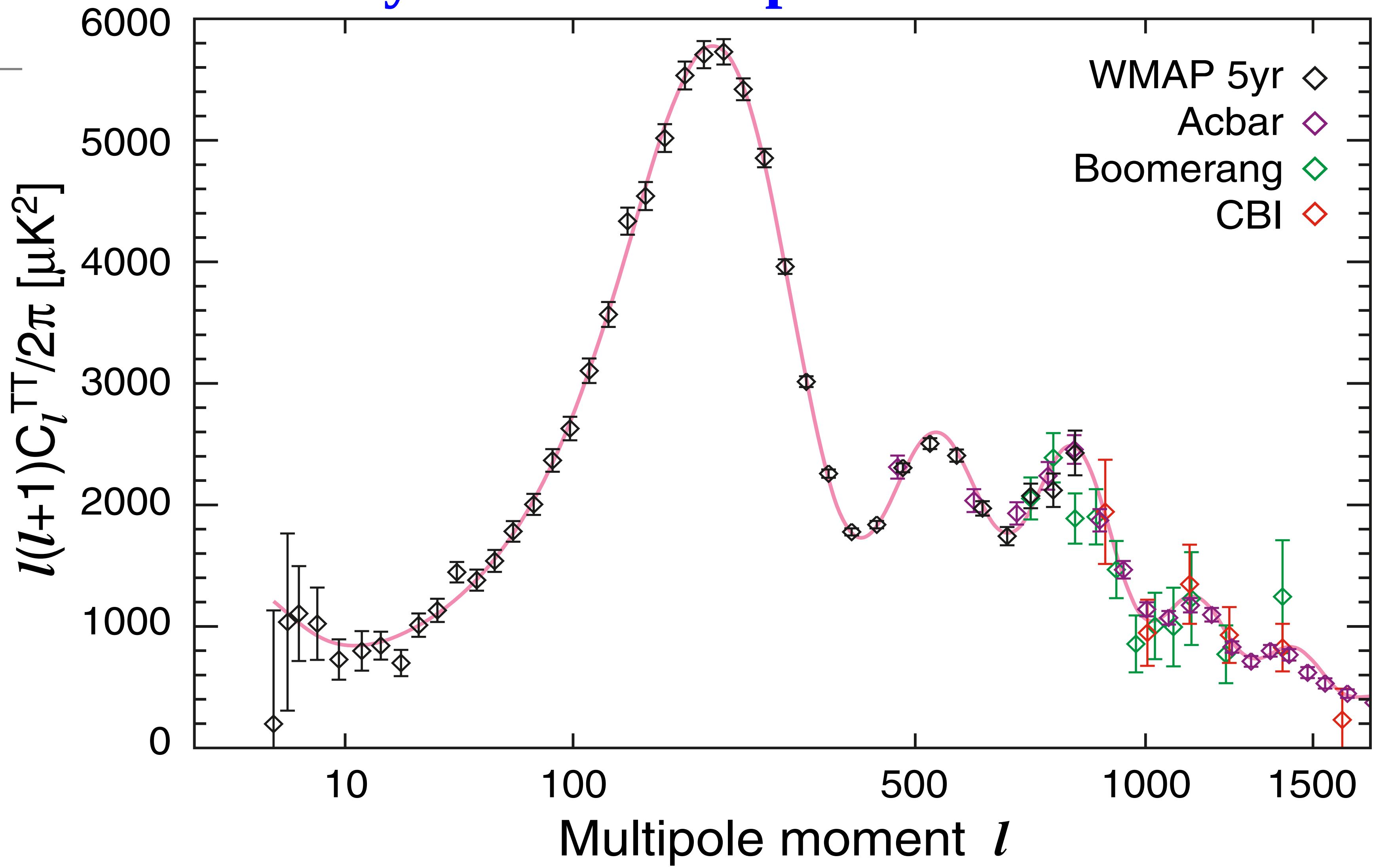
Photons temperature was then ~ 3000 K. Temperature today is $\simeq 2.725$ K (cooling down due to universe expansion).

CMB background almost homogeneous and isotropic with a black-body spectrum, plus small inhomogeneities $\sim 10^{-4}$. These small anisotropies were produced by quantum fluctuations in the inflationary era.

They have unique information about the first 10^{-36} sec of the Universe.

CMB anisotropies first detected in 1992 by COBE satellite. Later data by Boomerang et al. and especially WMAP.

WMAP 5 years data set plus other CMB data



Theory and observations nicely agree except for the lowest multipoles: the quadrupole suppression.

Primordial Gravitons detected from the CMB

Einstein's General Relativity predicts the existence of gravitational waves.

Astrophysical explosions produce such gravitational waves. Not detected so far because they are too weak.

Gravitons (= quantized gravitational waves) were produced in the inflationary era.

Effective theory of inflation gives a precise prediction for the amount of primordial gravitons produced:
4 to 5 % compared with the temperature CMB fluctuations.

They should be detectable from CMB observations through the so called tensor modes. They are much harder to detect than the known temperature fluctuations.

The Planck satellite will hopefully be able to detect the primordial gravitons (borderline !).

How the Universe took its present aspect?

The Universe was homogeneous and isotropic after inflation thanks to the fast and gigantic expansion stretching lenghts by a factor $e^{64} \simeq 10^{28}$.

The universe by the end of inflation is a extraordinarily hot plasma at $T \sim 10^{14}$ GeV $\sim 10^{27}$ K.

However, small ($\sim 10^{-5}$) quantum fluctuations were of course present.

These inflationary quantum fluctuations are the seeds of

- the structure formation in the universe: galaxies, clusters, stars, planets, ...
- the CMB anisotropies today.

That is, our present universe was built out of inflationary quantum fluctuations.

What is the nature of the Dark Matter?

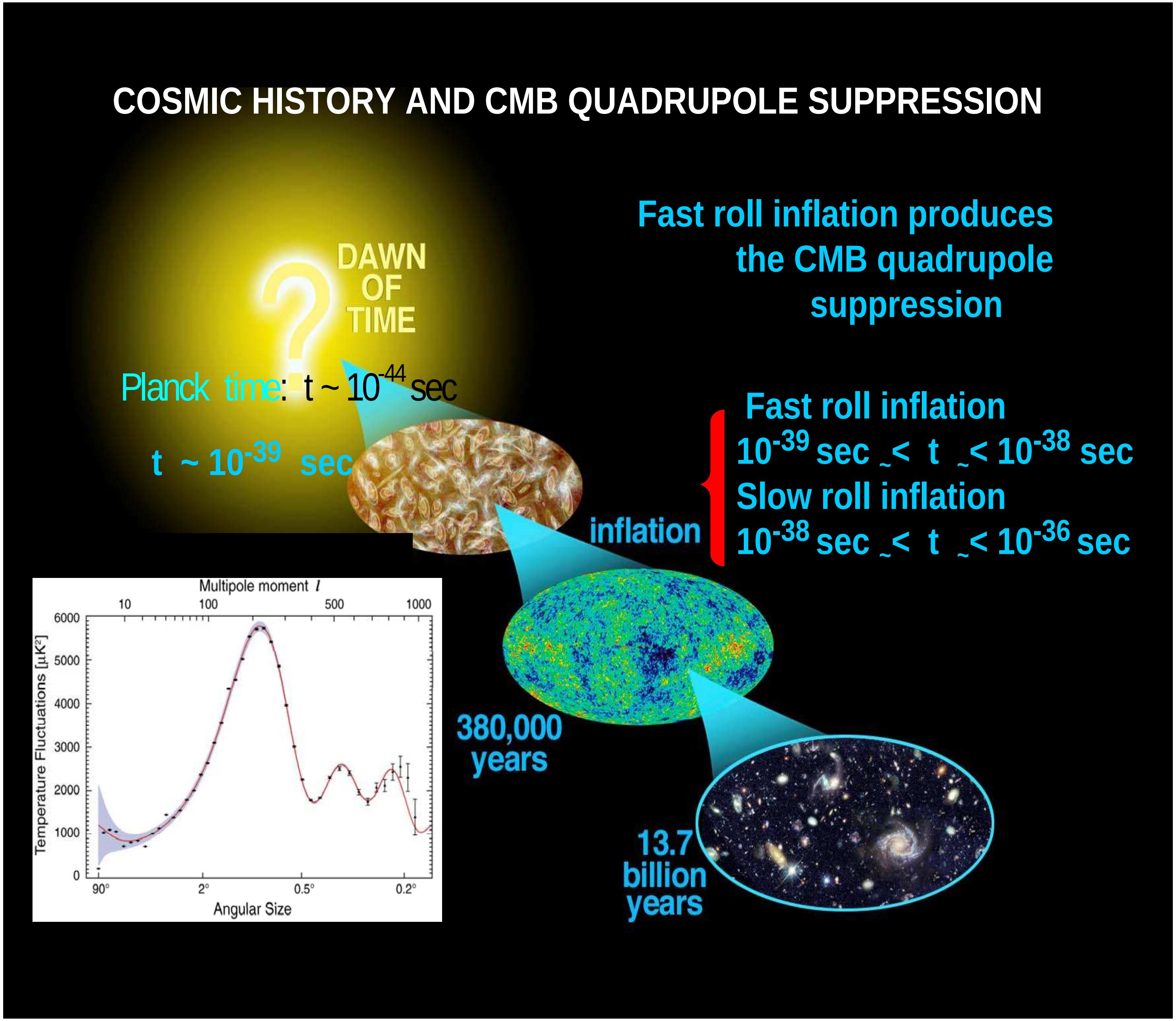
83% of the matter in the universe is Dark.
Only the DM gravitational effects are noticed and they are necessary to explain the present structure of the Universe.

DM (dark matter) particles must be neutral and so weakly interacting that no effects are so far detectable.

Extremely many candidates in particle physics models.

Theoretical analysis combined with astrophysical data from galaxy observations points towards a DM particle mass in the keV scale. keV = 1/511 electron mass.
keV scale DM particles reproduce:

- observed galaxy densities and velocity dispersions.
- observed galaxy density profiles.
- surface acceleration of gravity in DM dominated galaxies.


COSMIC HISTORY AND CMB QUADRUPOLE SUPPRESSION
Fast roll inflation produces the CMB quadrupole suppression
DAWN OF TIME
Planck time: t ~ 10^{-44} sec
t ~ 10^{-39} sec
Fast roll inflation
10^{-39} sec $\lesssim$ t $\lesssim 10^{-38}$ sec
Slow roll inflation
10^{-38} sec $\lesssim$ t $\lesssim 10^{-36}$ sec
inflation
380,000 years
13.7 billion years
Multipole moment l
10
100
500
1000
Temperature Fluctuations [μK²]
6000
5000
4000
3000
2000
1000
0
90°
2°
0.5°
0.2°
Angular Size

The Universe is our ultimate physics laboratory !!

THANK YOU VERY MUCH

FOR YOUR ATTENTION!!