Dernières Nouvelles de l'Univers

Norma G. SANCHEZ
DR CNRS, LERMA Observatoire de Paris

Ecole Internationale Daniel Chalonge

Autumn Open Session 27 NOV 2014

Observatoire de Paris

CONTENT OF THE UNIVERSE

ATOMS, the building blocks of stars and planets: represent only the **4.6%**

DARK MATTER comprises **23.4 %** of the universe. This matter, different from atoms, does not emit or absorb light. It has only been detected indirectly by its gravity.

72% of the Universe, is composed of **DARK ENERGY** that acts as a sort of an anti-gravity.
This energy, distinct from dark matter, is responsible for the present-day acceleration of the universal expansion, compatible with cosmological constant

CONTENTS

(I) The Standard Model of the Universe Includes Inflation

(II) THE NATURE OF DARK MATTER IN GALAXIES from Theory and Observations: Warm (keV scale) DM

(III) NEW: THE ESSENTIAL ROLE OF QUANTUM PHYSICS IN WDM GALAXIES:

Semiclassical framework: Analytical Results and Numerical (including analytical) Results

Observed Galaxy cores and structures from Fermionic WDM and more results.

(IV) NEW: The generic Galaxy types and properties from a same physical framework: From quantum (compact, dwarfs) to classical (dilute, large) galaxies. Equation of state

HIGHLIGHTS

(I)The Effective (Ginsburg-Landau) Theory of Inflation

PREDICTIONS vs Observations:

The Primordial Cosmic Banana: non-zero amount of primordial gravitons. And Forecasts for CMB exps.

NEW: BICEP2 !!!

(II) : TURNING POINT IN THE DARK MATTER PROBLEM: DARK MATTER IN GALAXIES from Theory and Observations: Warm (keV scale) dark matter

Physical Clarification and Simplification

GALAXY FORMATION AND EVOLUTION IN AGREEMENT WITH OBSERVATIONS

naturally re-insert in COSMOLOGY (LWDM)

Analytical Results and Numerical

NEW RESULTS

FERMIONIC QUANTUM WDM and GRAVITATION DETERMINE THE OBSERVED PHYSICAL GALAXY PROPERTIES

-> Dark matter (DM) is the main component of galaxies. Quantum mechanics is a cornerstone of physics from microscopic to macroscopic systems as quantum liquids He^3, white dwarf stars and neutron stars.

-> Recent study : Destri, de Vega, Sanchez, (New Astronomy 22, 39, 2013) suggest that quantum mechanics is also responsible of galaxy structures at the kpc scales and below: near the galaxy center, below 10 - 100 pc, the DM quantum effects are important for warm DM (WDM), that is for DM particles with masses in the keV scale.

-> A new approach to galaxy structure with results in remarkable agreement with observations:

(i) Dwarf galaxies turn to be quantum macroscopic objects for WDM supported against gravity by the WDM fermion pressure

(ii) Theoretical analytic framework based on Thomas-Fermi approach determine galaxy structure from the most compact dwarf galaxies to the largest dilute galaxies (spirals, ellipticals).

The obtained galaxy mass, halo radius, phase-space density, velocity dispersion, are fully consistent with observations.

(iii) Interestingly enough, a minimal galaxy mass and minimal velocity dispersion are found for DM dominated objects, which in turn imply an universal minimal mass m_min = 1.9 keV for the WDM particle.

- OBSERVED GALAXY CORES vs CDM CUSPS and WDM CORES-

- **Astronomical observations show that the DM galaxy density profiles are cored, that is, profiles which are flat at the center.**

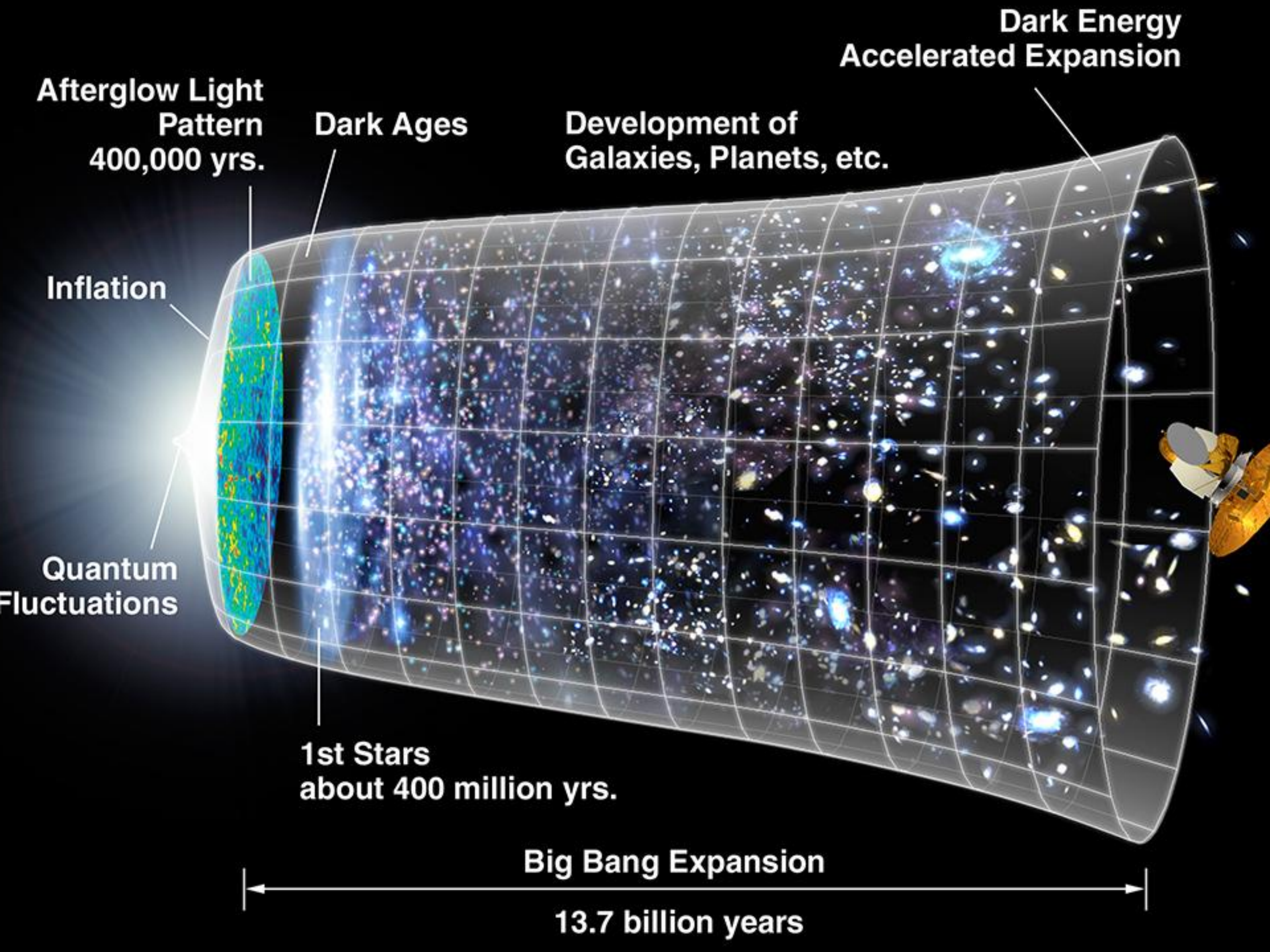
  On the contrary, N-body CDM simulations exhibit cusped density profiles, with a typical 1/r cusped behaviour near the galaxy center r = 0.

  Classical N-body WDM simulations exhibit cores but with sizes much smaller than the observed cores.

  We have recently developped a new approach to this problem thanks to Quantum Mechanics.

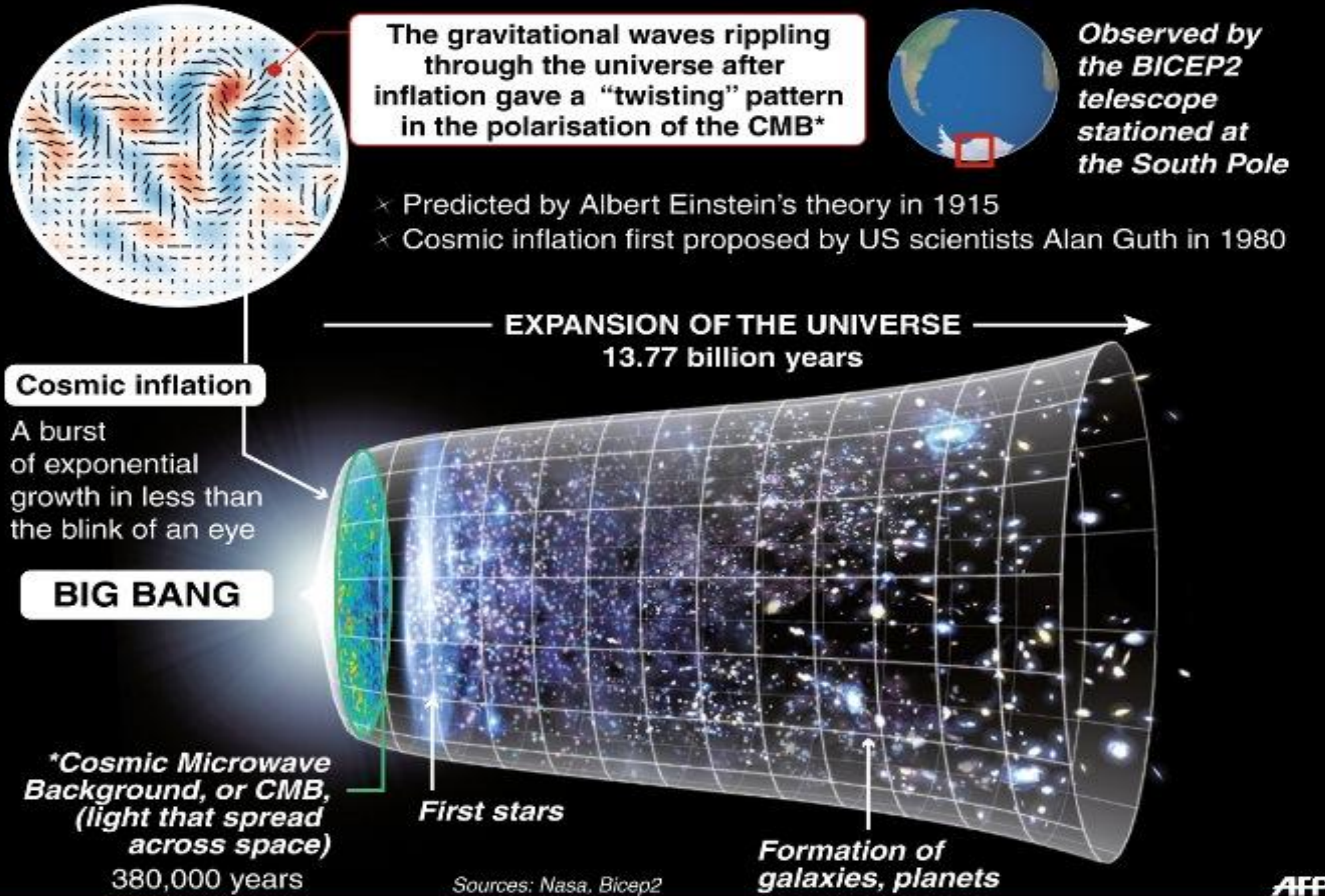
- **Fermions always provide a non vanishing pressure of quantum nature due to the combined action of the Pauli exclusion principle and Heisenberg uncertainty principle.**

- **Quantum effects for WDM fermions rule out the presence of galaxy cusps for WDM and enlarge the classical core sizes because their repulsive and non-local nature extend well beyond the small pc scales.**


Dark Energy
Accelerated Expansion
Afterglow Light
Pattern
400,000 yrs.
Dark Ages
Development of
Galaxies, Planets, etc.
Inflation
Quantum
Fluctuations
1st Stars
about 400 million yrs.
Big Bang Expansion
13.7 billion years

An echo of the Big Bang

US scientists have detected gravitational waves, the first direct evidence of a super-rapid expansion of the universe known as cosmic inflation



Quantum Fluctuations During Inflation and after

The Universe is homogeneous and isotropic after inflation thanks to the fast and gigantic expansion stretching lenghts by a factor $e^{62} \simeq 10^{27}$. By the end of inflation: $T \sim 10^{14}$ GeV.

Quantum fluctuations around the classical inflaton and FRW geometry were of course present.

These inflationary quantum fluctuations are the seeds of the structure formation and of the CMB anisotropies today: galaxies, clusters, stars, planets, ...

That is, our present universe was built out of inflationary quantum fluctuations. CMB anisotropies spectrum:

3×10^{-32}cm $< \lambda_{begin\,inflation} < 3 \times 10^{-28}$cm

$M_{Planck} \gtrsim 10^{18}$ GeV $> \lambda^{-1}_{begin\,inflation} > 10^{14}$ GeV.

total redshift since inflation begins till today $= 10^{56}$:

0.1 Mpc $< \lambda_{today} <$ 1 Gpc , 1 pc = 3×10^{18} cm $= 200000$ AU

THE ENERGY SCALE OF INFLATION IS THE

THE SCALE OF GRAVITY IN ITS SEMICLASSICAL REGIME

(OR THE SEMICLASSICAL GRAVITY TEMPERATURE)

(EQUIVALENT TO THE HAWKING TEMPERATURE)

The CMB allows to observe it
(while is not possible to observe for Black Holes)

The Energy Scale of Inflation

Grand Unification Idea (GUT)

- Renormalization group running of electromagnetic, weak and strong couplings shows that they all meet at $E_{GUT} \simeq 2 \times 10^{16}$ GeV
- Neutrino masses are explained by the see-saw mechanism: $m_\nu \sim \frac{M^2_{\rm Fermi}}{M_R}$ with $M_R \sim 10^{16}$ GeV.
- Inflation energy scale: $M \simeq 10^{16}$ GeV.

Conclusion: the GUT energy scale appears in at least three independent ways.

Moreover, moduli potentials: $V_{moduli} = M^4_{\rm SUSY} \; v\left(\frac{\phi}{M_{Pl}}\right)$

ressemble inflation potentials provided $M_{\rm SUSY} \sim 10^{16}$ GeV.
First observation of SUSY in nature??

From WMAP9 to Planck

Understanding the direction in which data are pointing:

- **PREDICTIONS for Planck**

- **Standard Model of the Universe**
- **Standard Single field Inflation**
- **NO RUNNING of the Primordial Spectral Index**
- **NO Primordial NON GAUSSIANITY**
- **N_{eff} neutrinos : --> Besides meV active neutrinos:**
- **1 or 2 sterile neutrinos**
- **Would opens the sterile neutrino Family:**
- **keV sterile neutrino –WDM-**

• Large Hadron Collider

- The first LHC results at 7-8 TeV, with the discovery of a candidate Higgs boson and the non observation of new particles or exotic phenomena, have made a big step towards completing the experimental confirmation of the Standard Model of particle physics.

- It is thus a good moment to recall our scientific predictions made several years ago on this matter because they are of full actuality.

Large Hadron Collider - LHC-

The results are completely in line with the Standard Model.

No evidence of SUSY at LHC

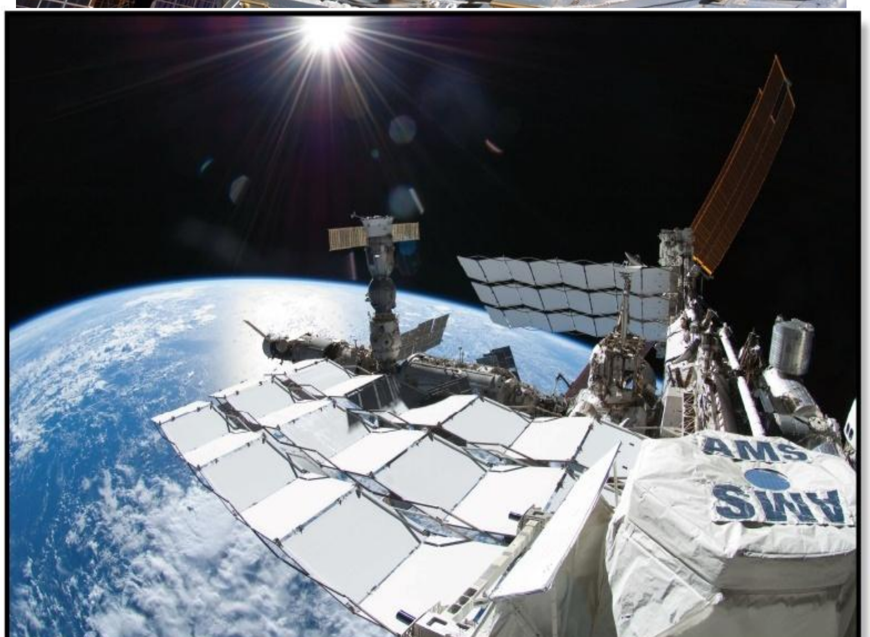
“*Supersymmetry may not be dead but these latest results have certainly put it into hospital.*"

(Prof Chris Parkes, spokesperson for the UK Participation in the LHCb experiment)

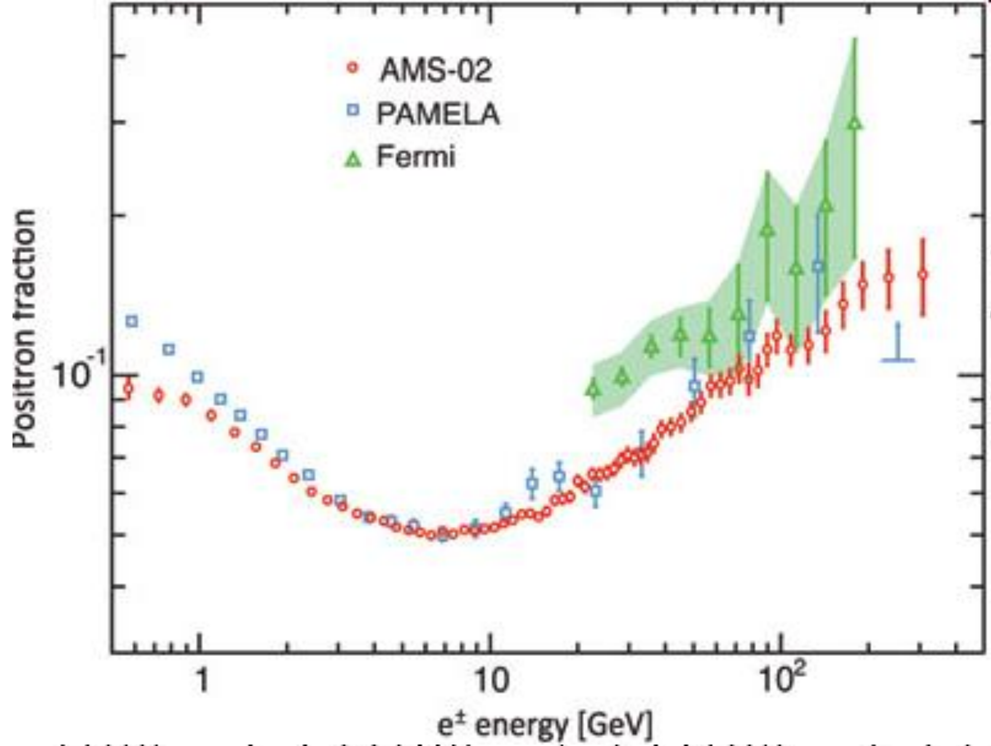
→Does Not support wimps -CDM-

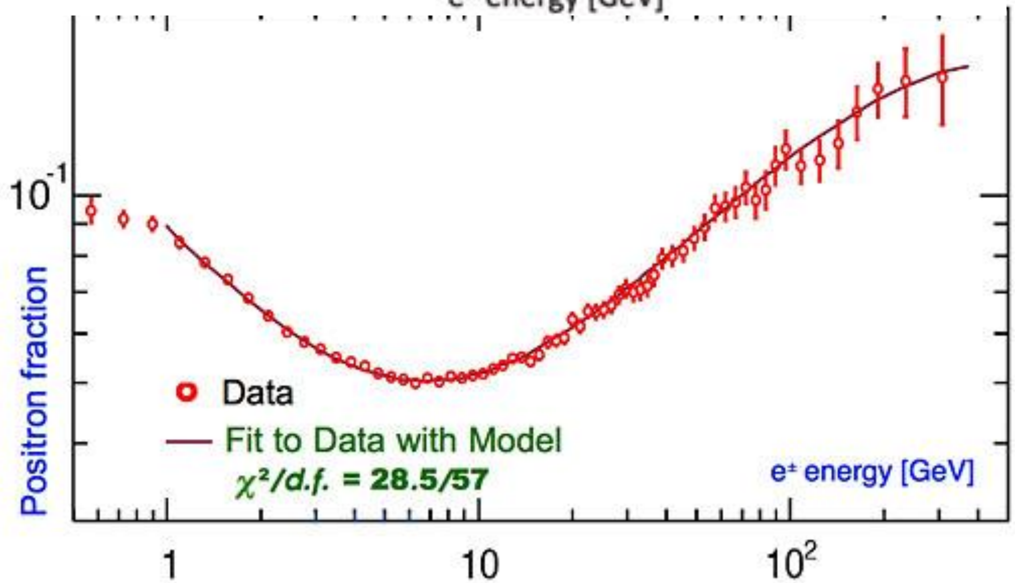
(In agreement with all dedicated wimp experiments at work from more than 20 years which have not found any wimp’s signal) **“So far researchers who are racing to find evidence of so called "new physics", ie non-standard models, have run into a series of dead ends”.**

ANTIMATTER IN SPACE - AMS on board ISS Alpha Magnet Spectrometer



NASA





Positron excess in cosmic rays are not related to DM physics but to astrophysical sources and astrophysical mechanisms and can be explained by them

LHC
AMS
PLANCK

Three beautiful and big experiments of performant instruments, technology, industry, achievements and successful operation which do not find the main scientific objective emphasized by them (for which they were designed)

- **Why No Experimental Detection of the DM particle has been reached so far ?**

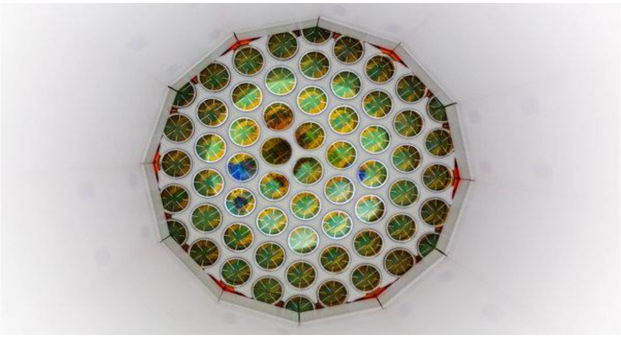
- **Because:**

- All experimental searches for DM particles are dedicated to CDM: wimps of m > 1 GeV,
- While the DM particle mass is in the keV scale .
- Moreover, past, present and future reports of signals of such CDM experiments **cannot be due to DM** because of the same reason.
- **The inconclusive signals in such experiments should be originated by phenomena of other kinds.**
- In addition, such signals contradict each other supporting the idea that they are **unrelated to any DM detection.**

LUX Large Underground Xenon Detector

30 October 2013

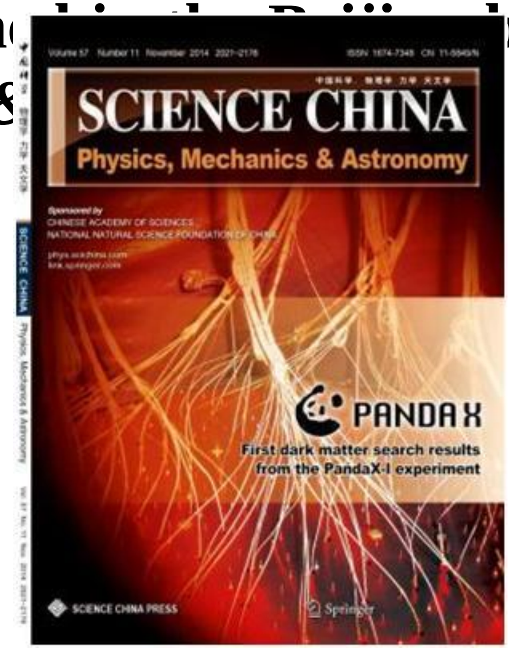
Dark Matter Experiment Has Detected Nothing, Researchers Say Proudly



- **They found no sign of WIMPS signals.**
  beyond the expected background noise.
- The experiment did so at far better sensitivities than any such experiment before it.

- **First dark matter search results from Chinese underground lab hosting**
- **PandaX-I experiment**
- **30 SEPTEMBER 2014**

Scientists across China and the United States collaborating on the PandaX search for dark matter from an underground lab in southwestern China report results from the first stage of the experiment in a new study publish… based journal *Science China Physics, Mechanics &…*



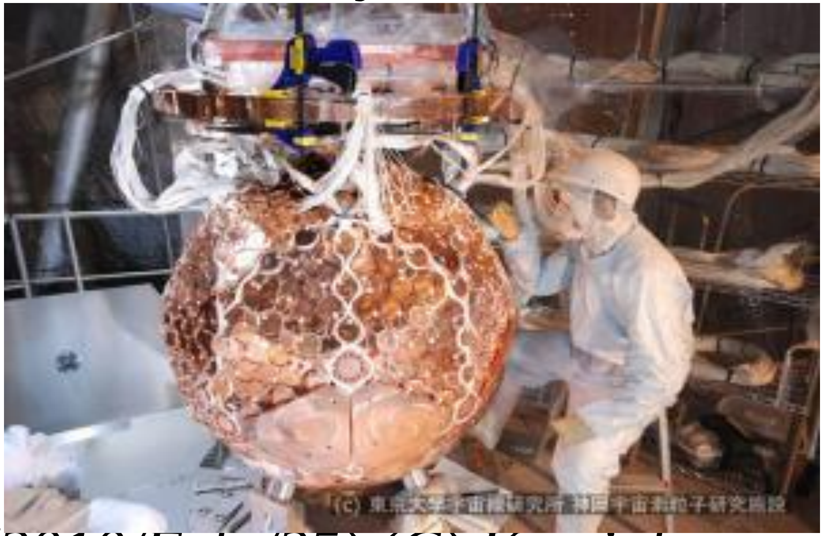
- **NEGATIVE RESULTS**
- **for Wimps**
- **China Science Press**

- **XMASS Recent News: October 6, 2014**

A Warm Dark Matter Search Using XMASS

(Originally published by the University of Tokyo) **The XMASS collaboration, led by Yoichiro Suzuki at the Kavli IPMU, has reported its latest results on the search for warm dark matter. Their results rule out the possibility that super-weakly interacting massive bosonic particles (bosonic super-WIMPs) This result was published in the September 19th issue of the Physical Review Letters as an Editors' Suggestion.**

NEGATIVE RESULTS for WIMPS



- *Construction of XMASS Ⅰ detector (2010/Feb./25) (C) Kamioka Observatory, ICRR (Institute for Cosmic Ray Research), University of Tokyo*

Sterile Neutrinos ν

Rhenium and Tritium beta decay (MARE, KATRIN).
Theoretical analysis: H J de V, O. Moreno, E. Moya de Guerra, M. Ramón Medrano, N. Sánchez,
Nucl. Phys. B866, 177 (2013).

[Other possibility to detect a sterile ν_s: a precise measure of nucleus recoil in tritium beta decay.]

Conclusion: the empty slot of right-handed neutrinos in the Standard Model of particle physics can be filled by keV-scale sterile neutrinos describing the DM.

An appealing mass neutrino hierarchy appears:

- Active neutrino: $\sim$ mili eV
- Light sterile neutrino: $\sim$ eV
- Dark Matter: $\sim$ keV
- Unstable sterile neutrino: $\sim$ MeV....

LHC

AMS

PLANCK

Three beautiful and big experiments of performant instruments, technology, industry, achievements and successful operation which do not find the main scientific objective emphasized by them (for which they were designed)

Recent News on Cosmological Observables

Before 2013: Hubble constant $H_0 = 73.8 \pm 2.4 \; \frac{\text{km}}{\text{s}} \; \frac{1}{\text{Mpc}}$ from direct observations of Cepheids by HST, $\Omega_m = 0.27 \pm 0.03$. A G Riess et al. ApJ 730, 119 (2011).

Planck 2013: $H_0 = 67.3 \pm 1.2 \; \frac{\text{km}}{\text{s}} \; \frac{1}{\text{Mpc}}$. $\Omega_m = 0.32 \pm 0.02$.

Planck assumed here only three massless neutrinos and no sterile neutrinos ν_s.

There is today strong evidence for ν_s with $m_s \sim$ eV from short baseline experiments (reactors, MiniBoone, LSND).

Adding one ν_s yields:

$H_0 = 70 \pm 1.2 \; \frac{\text{km}}{\text{s}} \; \frac{1}{\text{Mpc}}$. $\Omega_m = 0.30 \pm 0.01$ for $m_s = 0.4$ eV.

These values for H_0 and Ω_m are compatible with the direct astronomical measurements.

M. Wyman et al. PRL. 112, 051302 (2014), J. Hamann & J. Haserkamp, JCAP,10,044H (2013) R. Battye & A. Moss,

Effective Theory of Inflation (ETI) confirmed by Planck

Quantity	ETI Prediction	Planck 2013
Spectral index $1 - n_s$	order $1/N = 0.02$	0.04
Running $dn_s/dlnk$	order $1/N^2 = 0.0004$	< 0.01
Non-Gaussianity f_{NL}	order $1/N = 0.02$	< 6
	ETI + WMAP+LSS	
tensor/scalar ratio r	r > 0.02	< 0.11 see BICEP
inflaton potential curvature $V''(0)$	$V''(0) < 0$	$V''(0) < 0$

ETI + WMAP+LSS means the MCMC analysis combining the ETI with WMAP and LSS data. Such analysis calls for an inflaton potential with negative curvature at horizon exit. The double well potential is favoured (new inflation).
D. Boyanovsky, C. Destri, H. J. de Vega, N. G. Sanchez, arXiv:0901.0549, IJMPA 24, 3669-3864 (2009).

Two key observable numbers :

associated to the primordial density and primordial gravitons :

$$n_s = 0.9608 \,, \quad r$$

PREDICTIONS

$r > 0.021$

DdS: Destri, de Vega, Sanchez & from WMAP data (PRD 2008)

BICEP2 result 2014: r about 0.20-0.16

THE PRIMORDIAL GRAVITONS

LOWER BOUND on r (2008)

Our theory input (Effective Theory Inflation) in the MCMC data analysis of WMAP5+LSS+SN data).

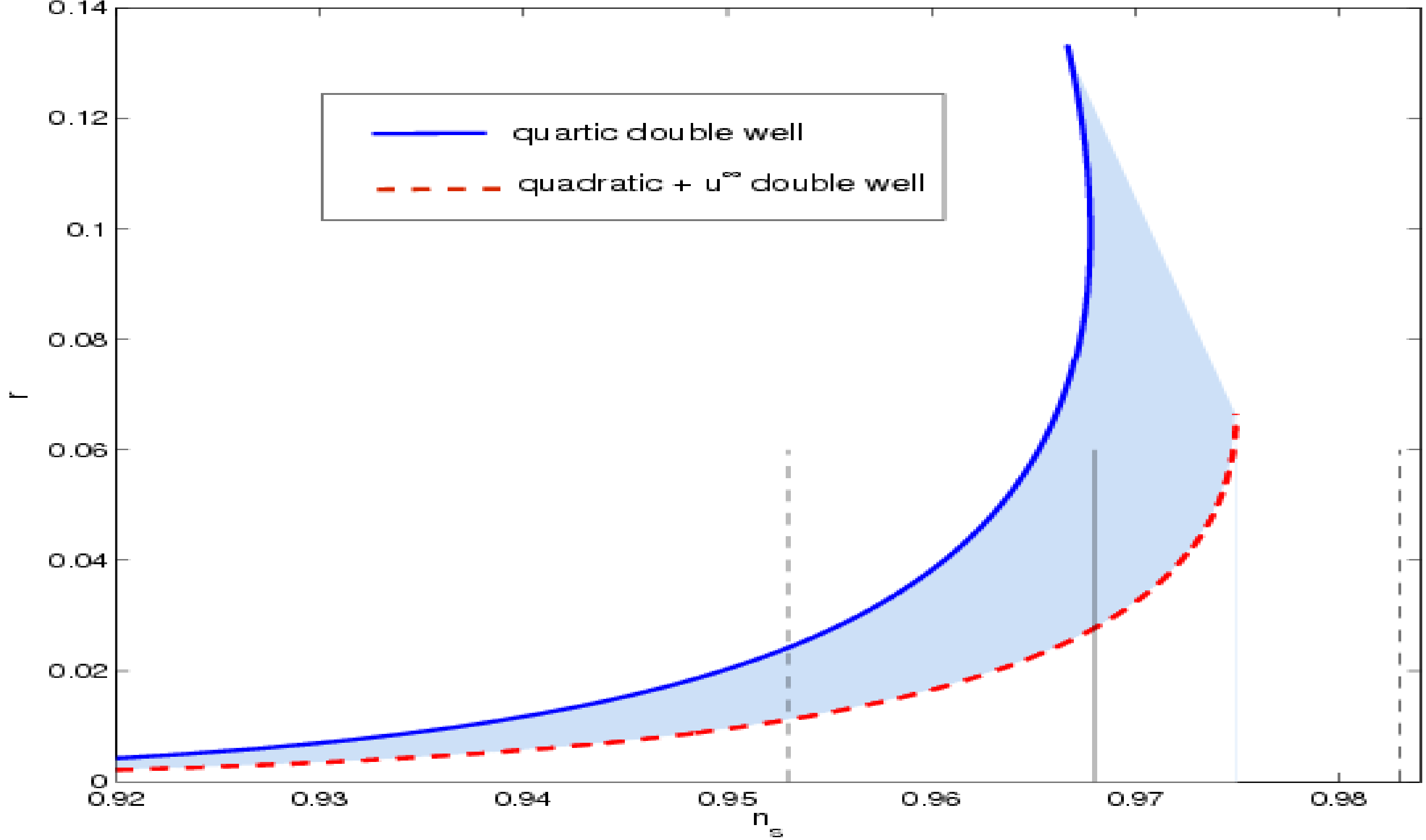
C. Destri, H J de Vega, N G Sanchez, Phys Rev D77, 043509 (2008) shows:

Besides the upper bound for r (tensor to scalar ratio) $r < 0.22$, we find a clear peak in the r distribution and we obtain a lower bound

$r > 0.023$ at 95% CL and

$r > 0.046$ at 68% CL.

For the other cosmological parameters, both analysis agree.

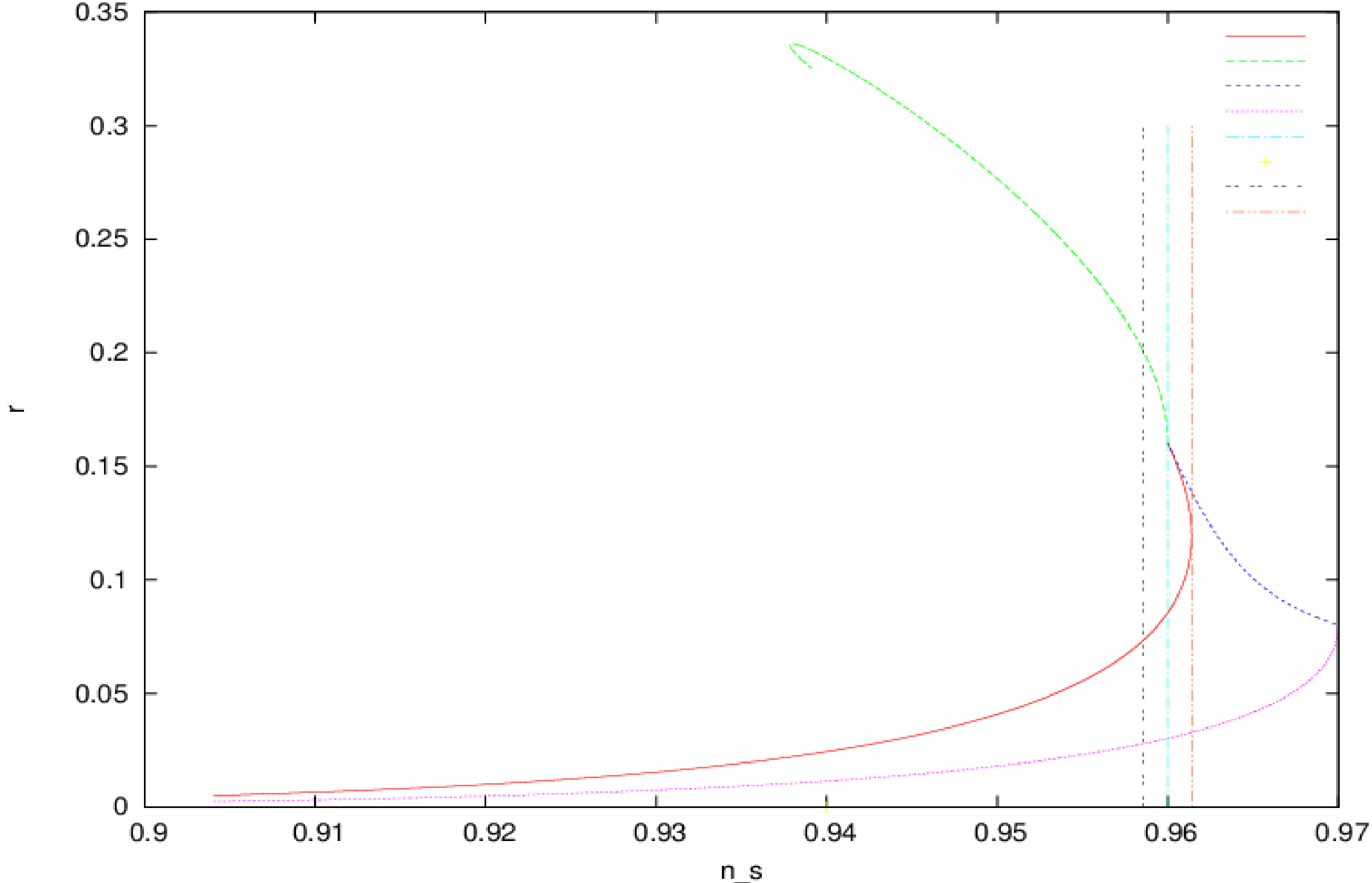


THE PRIMORDIAL COSMIC BANANA

The tensor to scalar ratio r (primordial gravitons) versus the scalar spectral index n_s. The amount of r is always non zero

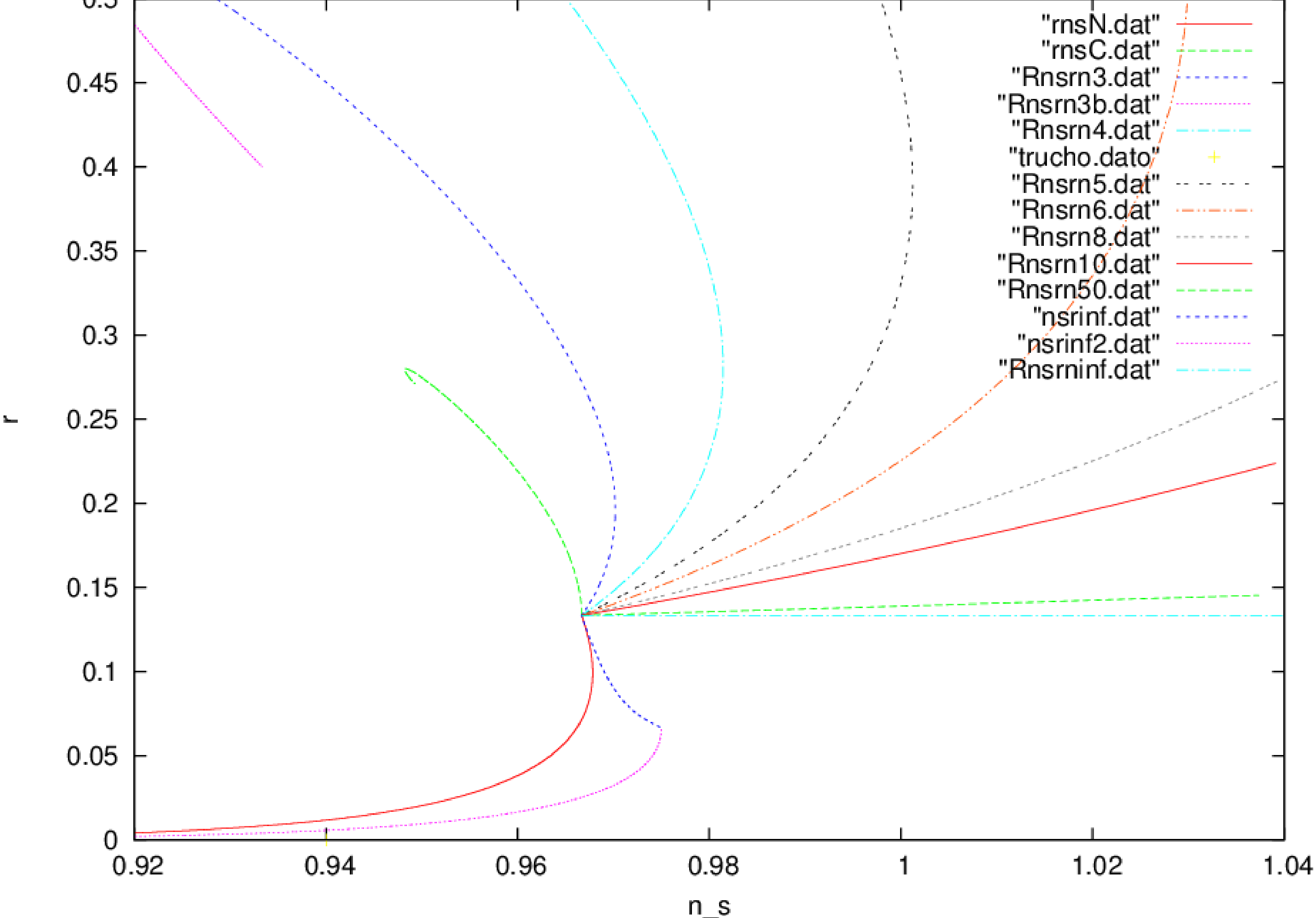
H.J. de Vega, C. Destri, N.G. Sanchez, Annals Phys 326, 578(2011)

Single and Double Well Inflaton Potentials



The cosmic banana for double well potentials (N=50).

$n_s = 0.96 \pm 0.014$ Planck + BAO + sterile (Melchiorri et al.


0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0.92
0.94
0.96
0.98
1
1.02
1.04
n_s
r
"rnsN.dat"
"rnsC.dat"
"Rnsrn3.dat"
"Rnsrn3b.dat"
"Rnsrn4.dat"
"trucho.dato"
"Rnsrn5.dat"
"Rnsrn6.dat"
"Rnsrn8.dat"
"Rnsrn10.dat"
"Rnsrn50.dat"
"nsrinf.dat"
"nsrinf2.dat"
"Rnsrninf.dat"

Dark Matter Particles

DM particles decouple due to the universe expansion, their distribution function freezes out at decoupling.

The characteristic length scale is the free streaming scale (or Jeans' scale). For DM particles decoupling UR:

$r_{Jeans} = 57.2 \, \mathrm{kpc} \, \frac{\mathrm{keV}}{m} \left(\frac{100}{g_d}\right)^{\frac{1}{3}}$, solving the linear Boltz-V eqs.

$g_d =$ number of UR degrees of freedom at decoupling.

DM particles can freely propagate over distances of the order of the free streaming scale.

Therefore, structures at scales smaller or of the order of r_{Jeans} are erased.

The size of the DM galaxy cores is in the ~ 50 kpc scale $\Rightarrow \; m$ should be in the keV scale (WDM particles).

For neutrinos $m \sim$ eV HDM particles
$r_{Jeans} \sim 60$ Mpc $\Rightarrow$ NO GALAXIES FORMED.

Dark Matter: from primordial fluctuations to Galaxies

- ❖ **Cold (CDM): small velocity dispersion: small structures form first, bottom-up hierarchical growth formation, *too heavy (GeV)***
- ❖ **Hot (HDM) : large velocity dispersion: big structures form first, top-down, fragmentation, ruled out, *too light* (eV)**

Warm (WDM): ``in between'', *right mass scale,* (keV)

ΛWDM Concordance Model:

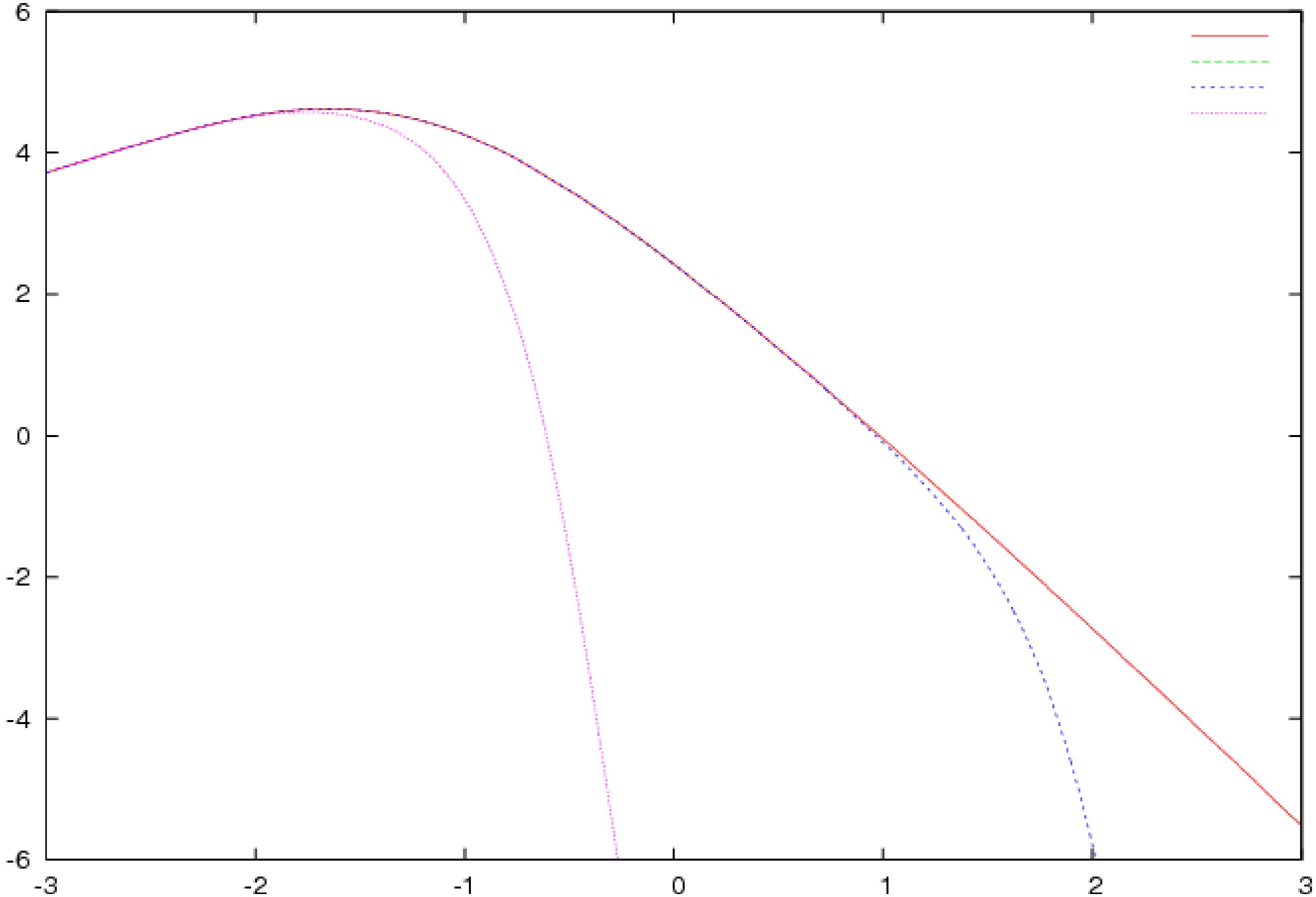
CMB + LSS + SSS Observations

DM is WARM and COLLISIONLESS

***CDM Problems*:**

- **"clumpy halo problem", large number of satellite galaxies**
- **"satellite problem", overabundance of small structures**
- **ρ (r) ~ 1 / r (cusp)**
- **And other problems…..**

Linear primordial power today $P(k)$ vs. k Mpc h

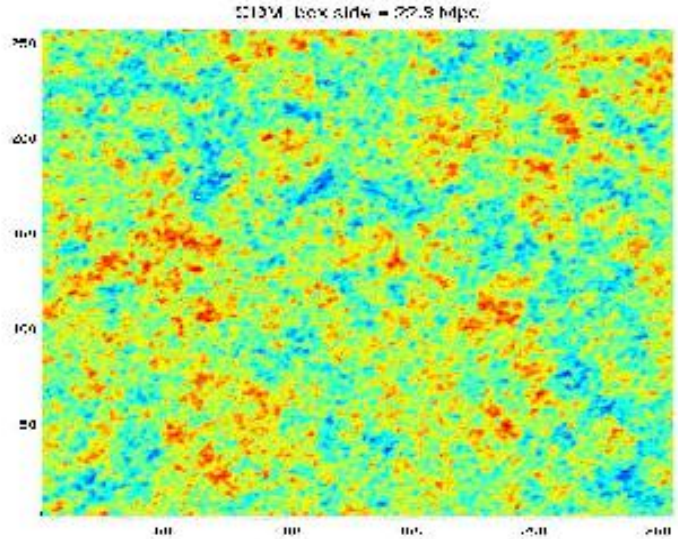


$\log_{10} P(k)$ vs. $\log_{10}[k \text{ Mpc } h]$ for WIMPS, 1 keV DM particles and 10 eV DM particles. $P(k) = P_0 \, k^{n_s} \, T^2(k)$.

$P(k)$ cutted for 1 keV DM particles on scales $\lesssim 100$ kpc.

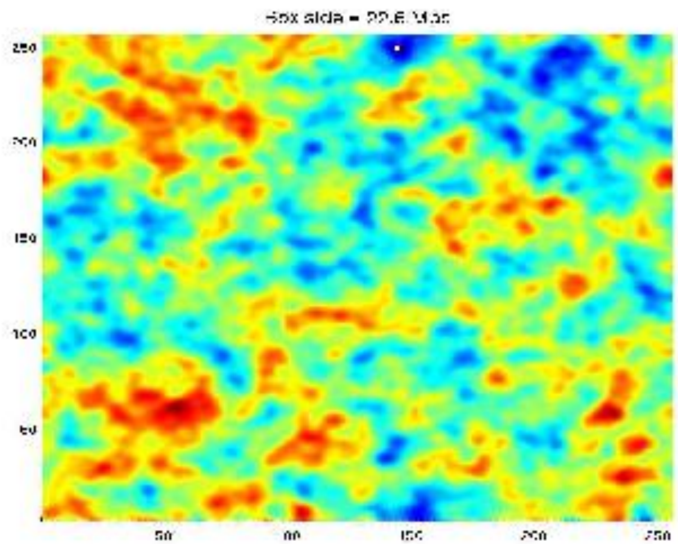
Transfer function in the MD era from Gilbert integral eq.

WDM vs. CDM linear fluctuations today



Box side = 22.6 Mpc. [C. Destri, private communication].

WDM:



WARM DARK MATTER REPRODUCE

→OBSERVED GALAXY DENSITIES AND VELOCITY DISPERSIONS

→SOLVES the OVERABUNDANCE (“satellite) PROBLEM

->OBSERVED SURFACE DENSITY VALUES OF DARK MATTER DOMINATED GALAXIES

→OBSERVED GALAXY CORED DENSITY PROFILES : QUANTUM MECHANICS

Dwarf galaxies as quantum objects

de Broglie wavelength of DM particles $\lambda_{dB} = \frac{\hbar}{m\,\sigma}$

$d =$ mean distance between particles,
$\sigma =$ DM mean velocity

$$d = \left(\frac{m}{\rho}\right)^{\frac{1}{3}} \quad , \quad Q = \rho/\sigma^3 \quad , \quad Q = \text{phase space density.}$$

ratio: $$\mathcal{R} = \frac{\lambda_{dB}}{d} = \hbar \left(\frac{Q}{m^4}\right)^{\frac{1}{3}}$$

Observed values: $2 \times 10^{-3} < \mathcal{R} \left(\frac{m}{\text{keV}}\right)^{\frac{1}{3}} < 1.4$

The larger $\mathcal{R}$ is for ultracompact dwarfs.
The smaller $\mathcal{R}$ is for big spirals.

$\mathcal{R}$ near unity (or above) means a QUANTUM OBJECT.

Observations alone show that compact dwarf galaxies are quantum objects (for WDM).

The quantum radius r_q for different kinds of DM

DM type	DM particle mass	r_q	
CDM	$1 - 100$ GeV	$1 - 10^4$ meters	in practice zero
WDM	$1 - 10$ keV	$0.1 - 1$ pc	compatible with observed cores
HDM	$1 - 10$ eV	kpc - Mpc	too big !

RESULTS

All the obtained density profiles are cored.

The Core Sizes are in agreement with the observations

from the compact galaxies where r_h ~ 20 pc till the spiral and elliptical galaxies where r_h ~ 0.2 - 60 kpc.

The larger and positive is the chemical potential $\nu(0)$, the smaller is the core. The minimal one arises in the degenerate case $\nu(0)$ --> to +infinity (compact dwarf galaxies).

And

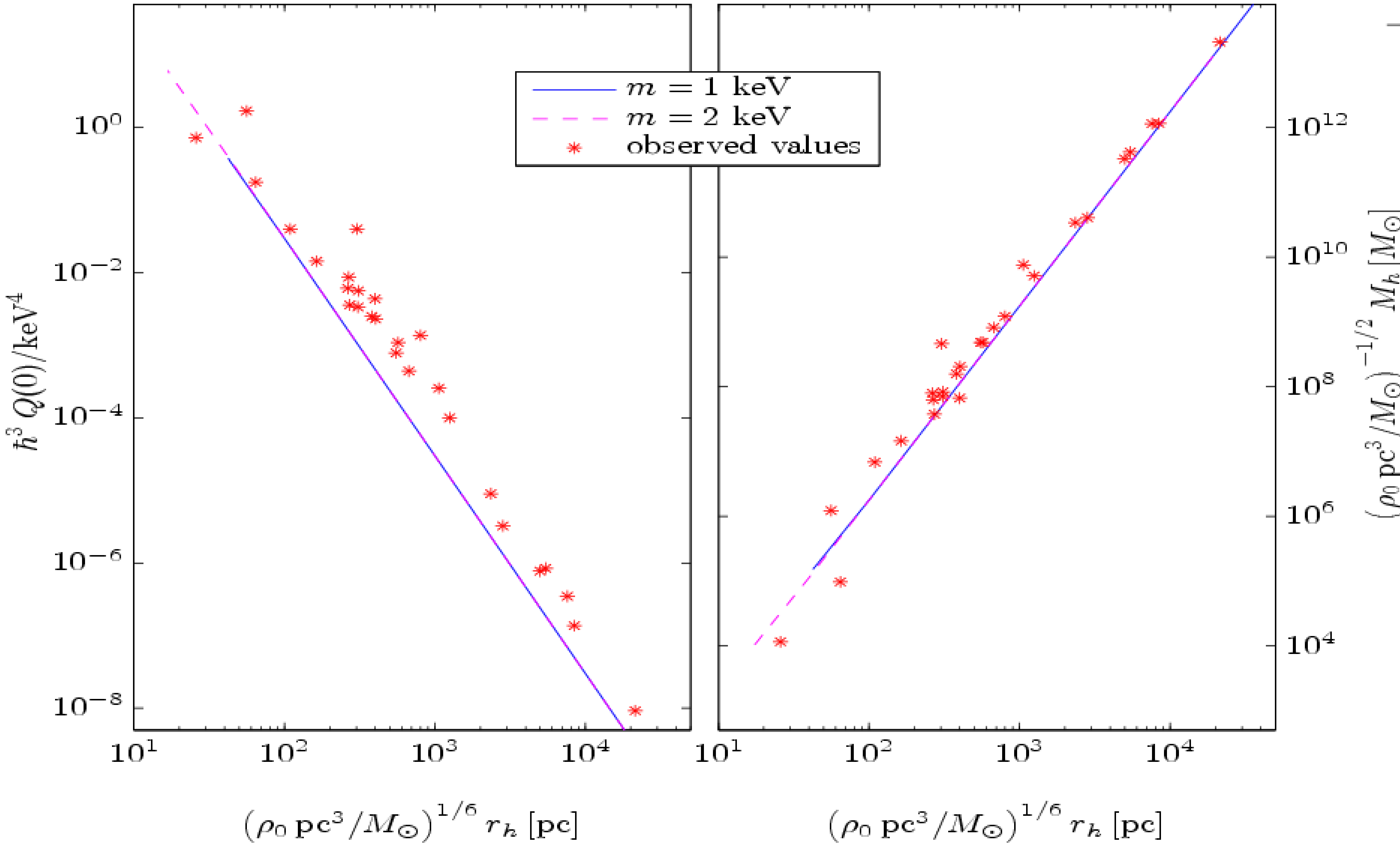
The Phase-space Density

The Galaxy halo Masses.

Agreement is found in all the range of galaxies for a DM particle mass m around 2 keV.

Error bars of the observational data are not shown but they are at least about 10-20 %.

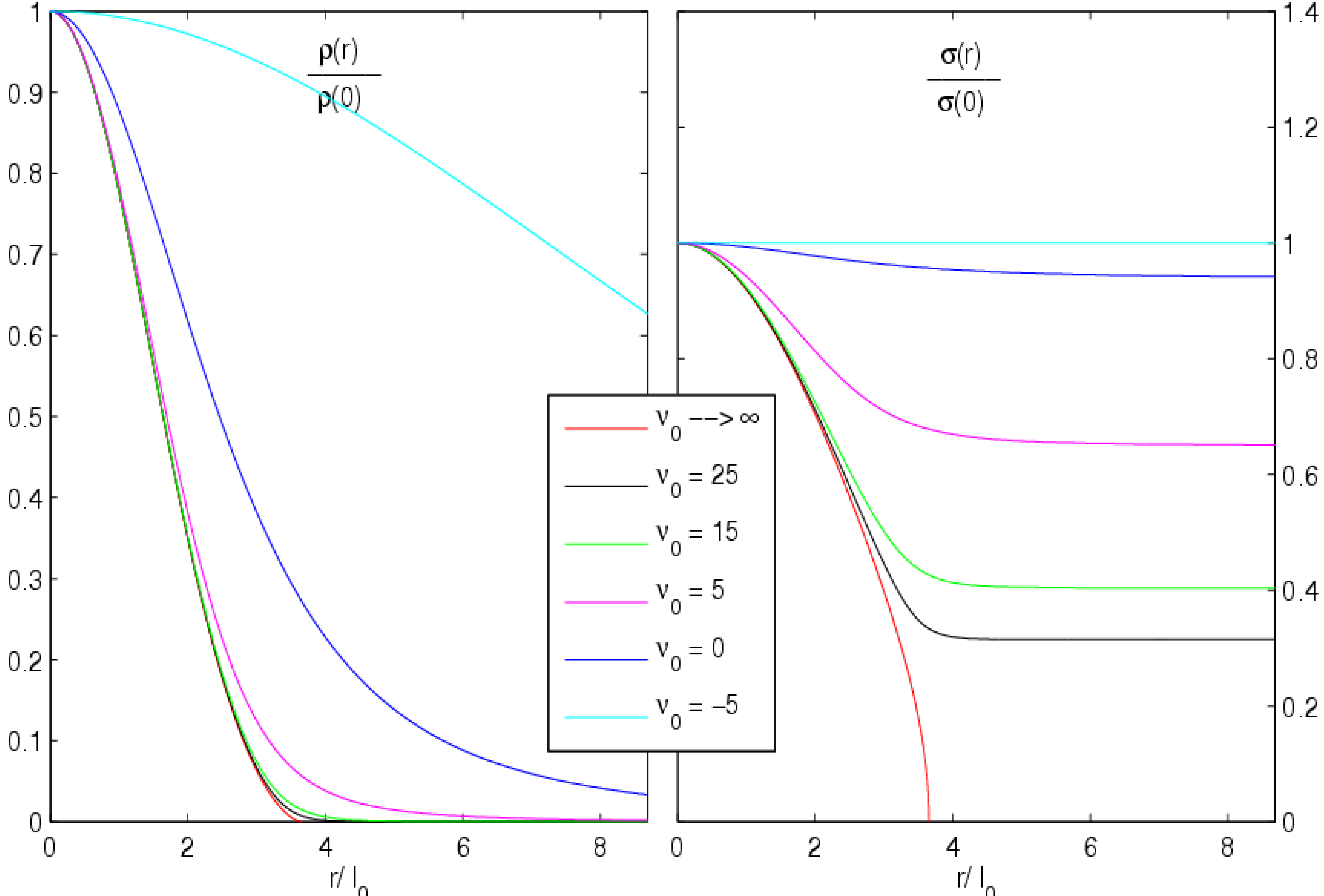
Q vs. halo radius. Galaxy observations vs. Thomas-Fermi



observed $Q = \rho/\sigma^3$ from stars are upper bounds for DM Q

Density and velocity profiles from Thomas-Fermi

Cored density profile and velocity profile obtained from Thomas-Fermi.



THE MINIMAL GALAXY MASS

A minimal galaxy mass and minimal velocity dispersion are found.

This in turn implies a minimal mass m_min =1.91 keV for the WDM particle.

This minimal WDM mass is a universal value, independent of the WDM particle physics model because only relies on the degenerate quantum fermion state, which is universal whatever is the non-degenerate regime.

These results and the observed halo radius and mass of the compact galaxies also provide further indication that the WDM particle mass m is approximately around 2 keV.

More precise data will make this estimation more precise.

Minimal galaxy mass from degenerate WDM

The halo radius, the velocity dispersion and the galaxy mass take their minimum values for degenerate WDM:

$$r_{h\ min} = 24.51\ldots \ \mathrm{pc} \ \left(\frac{m}{\mathrm{keV}}\right)^{\frac{4}{3}} \ \left[\rho(0) \ \frac{\mathrm{pc}^3}{M_\odot}\right]^{\frac{1}{6}}$$

$$M_{min} = 2.939\ldots \ 10^5 \ M_\odot \ \left(\frac{\mathrm{keV}}{m}\right)^4 \ \sqrt{\rho(0) \ \frac{\mathrm{pc}^3}{M_\odot}}$$

$$\sigma_{min}(0) = 2.751\ldots \ \frac{\mathrm{km}}{\mathrm{s}} \ \left(\frac{\mathrm{keV}}{m}\right)^{\frac{4}{3}} \ \left[\rho(0) \ \frac{\mathrm{pc}^3}{M_\odot}\right]^{\frac{1}{3}} \ .$$

These minimum values correspond to the observations of compact dwarf galaxies.

Lightest known compact dwarf galaxy is Willman I:

$M_{Willman\ I} = 2.9 \ 10^4 \ M_\odot$

Imposing $M_{Willman\ I} > M_{min}$ yields the lower bound for the WDM particle mass: $m > 1.91$ keV.

WARM DARK MATTER REPRODUCE

→OBSERVED GALAXY DENSITIES AND VELOCITY DISPERSIONS

→OBSERVED GALAXY CORED DENSITY PROFILES

->OBSERVED SURFACE DENSITY VALUES OF DARK MATTER DOMINATED GALAXIES

→SOLVES the OVERABUNDANCE ("satellite) PROBLEM and the CUSPS vs CORES Problem

• WDM OVERALL CONCLUSION

- **To conclude, we find it is highly remarkable that in the context of warm dark matter, the quantum description provided by this semiclassical framework, (quantum WDM and classical gravitation), is able to reproduce such broad variety of galaxies.**

- **The resulting galaxy, halo radius, galaxy masses and velocity dispersion are fully consistent with observations for all different types of galaxies. Fermionic WDM treated quantum mechanically, as it must be, is able to reproduce the observed galactic cores and their sizes. In addition, WDM simulations produce the right DM structures in agreement with observations for scales > kpc.**

IN PROGRESS

H. J. de Vega, N. G. Sanchez:

BLACK HOLES FORMED
by WDM and BARYONS

(GALACTIC SUPERMASSIVE, STELLAR)

Galaxy Structure from Classical Cosmological Boltzmann-Vlasov equations:
Generalized Larson equations

And other results…..

keV Sterile Neutrino Warm Dark Matter

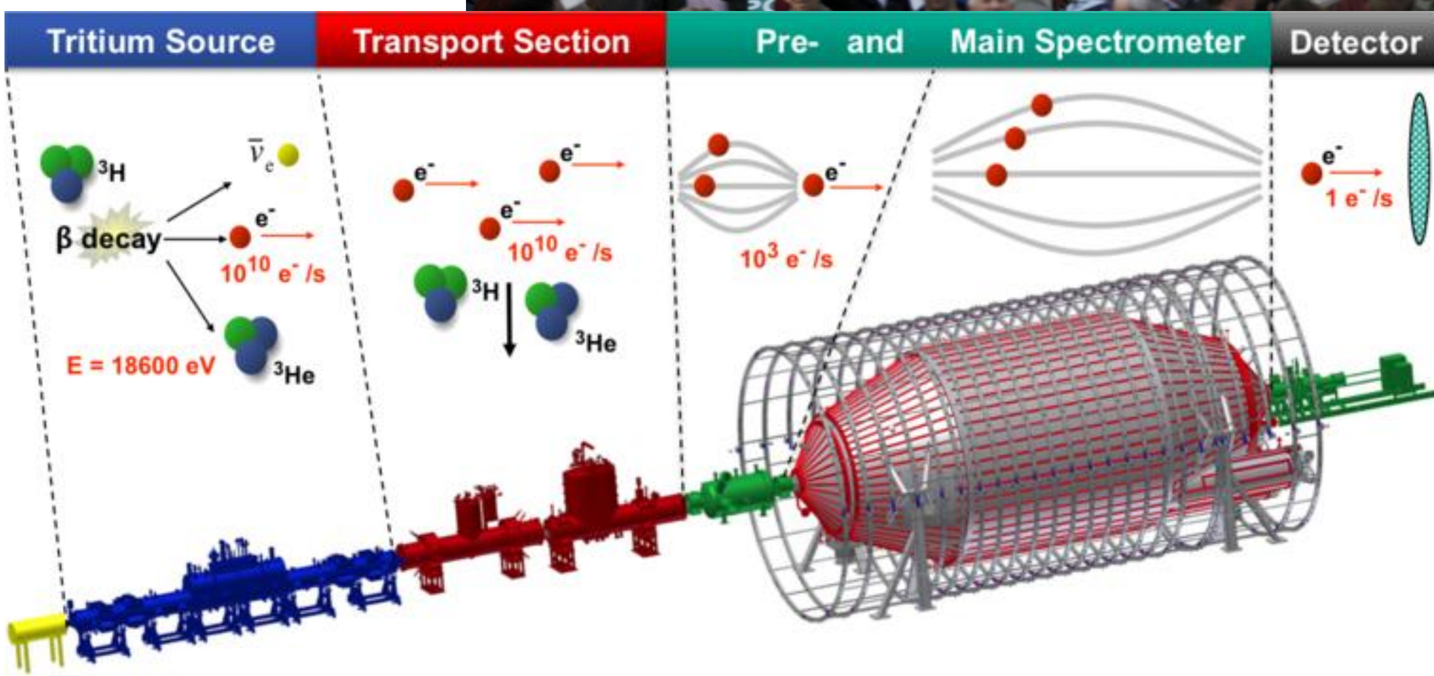
Sterile neutrinos can decay into an active-like neutrino and a monochromatic X-ray photon with an energy half the mass of the sterile neutrino. Observing the X-ray photon provides a way to observe sterile neutrinos in DM halos.

WDM keV sterile neutrinos can be copiously produced in the supernovae cores. SN stringently constrain the neutrino mixing angle squared to be 10^{-9} for m > 100 keV (in order to avoid excessive energy lost) but for smaller masses the SN bound is not so direct. Within the models worked out till now, mixing angles are essentially unconstrained by SN in the keV mass range.

Sterile neutrinos are produced out of thermal equilibrium and their production can be non-resonant (in the absence of lepton asymmetries) or resonantly enhanced (if lepton asymmetries are present).

KATRIN

Karlsruhe Tritium Neutrino Experiment



How to detect sterile neutrinos?

Sterile neutrinos can be detected in beta decay and in electron capture (EC) when a ν_s with mass in the keV sca is produced instead of an active ν_e.

Beta decay: the electron spectrum is slightly modified at energies around the mass ($\sim$ keV) of the ν_s.

$$^3H_1 \Longrightarrow {}^3He_2 + e^- + \bar{\nu}_e \quad , \quad {}^{187}Re \Longrightarrow {}^{187}Os + e^- + \bar{\nu}_e.$$

The electron energy spectrum is observed.

Electron capture: $^{163}Ho + e^- \Longrightarrow {}^{163}Dy^* + \nu_e$
The nonradiative de-excitation of the Dy^* is observed and different for ν_s in the keV range than for active ν_e.

Experiments that may detect sterile neutrinos:

MARE (Milano), KATRIN (Karlsruhe), PTOLEMY (Princeton), ECHo (Heidelberg).

They search the mass of the ordinary neutrino.

École Internationale Daniel Chalonge

Science with great intellectual endeavour and a human face
La science qui donne envie. Une grande aventure scientifique et humaine

23 Years of Activity. Calling for understanding

PROGRAMME
OF THE YEAR 2014

14 MARCH 2014: Opening Session / Session ouverte de culture scientifique : "Présentation du programme 2014 et des dernières nouvelles scientifiques de l'univers" *(Batiment Perrault, Observatoire de Paris)*

22 MAY 2014: Spring Open Session of scientific culture / Session ouverte de printemps de culture scientifique interdisciplinaire : "L'homme et l'univers" *(Bâtiment Perrault, Observatoire de Paris)*

4-7 JUNE 2014: Chalonge Meudon workshop: "From large to small scale structures in agreement with observations: CMB, WDM, galaxies, black holes, neutrinos and sterile neutrinos" *(Château de Meudon - CIAS, Meudon)*

22-25 JULY 2014: The 18th Paris cosmology colloquium Chalonge 2014: "Latest news from the universe: Λ WDM, CMB, dark matter, Λ dark energy, neutrinos and sterile neutrinos" *(Bâtiment Perrault, Observatoire de Paris)*

25 JULY 2014: Summer Open Session of scientific culture / Session ouverte d'Été de culture scientifique : A surprise session

AUTOMNE 2014: Cycle Les grandes questions posées aujourd'hui à la science : "Où va la science ?" *(Cité Internationale Universitaire de Paris)*

17-18 OCTOBER 2014: Chalonge Turin session: "Latest news from the universe: dark matter, galaxies and particle physics" *(Palazzo de l'Università & Accademia delle Scienze, Piamonte region, Turin, Italy)*

27-28 NOVEMBER 2014: Concluding session & Avant-première 2015

Welcome to the Chalonge School: A laboratory of ideas, Research, Training, Scientific Culture

A beacon pioneering and developing research, projects and training. The programme offers invaluable international current research view at the forefront of astrophysics and cosmology, international contacts at the highest level and a careful interdisciplinarity, with both theory and observations.

The programme is open to researchers, post-docs and advanced students of the different disciplines in the field, both theorists, experimentalists and observers. Advanced students, post-docs, young researchers are encouraged to participate. The programme includes scientific culture events with the latest results and exhibitions.

The Chalonge School Medal is coined exclusively for the Chalonge School by the *Hôtel de la Monnaie de Paris* (the French Mint). Only ten Chalonge medals have been awarded in the 22 year school history.

Awarded Daniel Chalonge Medals

Subramanyan CHANDRASEKHAR, *Nobel prize of physics*
Bruno PONTECORVO
George SMOOT, *Nobel prize of physics*
Carlos FRENK
Anthony LASENBY
Bernard SADOULET, *Fellow of the USA Academy of Arts And Sciences*
Peter BIERMANN
John MATHER, *Nobel prize of physics*
Brian SCHMIDT, *Nobel prize of Physics*
Gérad GILMORE, *Fellow of the UK Royal Society*

The Chalonge School Team

Science Organizers
Norma G. SANCHEZ, Héctor J. DE VEGA, Maria C. FALVELLA, Alba ZANINI, Marina RAMON MEDRANO, Annalisa PERISSA and other colleagues.

Engineering and Technical Support
Djilali ZIDANI, François SEVRE, Nicole LETOURNEUR, Jean-Pierre MICHEL, Sylvain CNUDDE and other colleagues.

School courses, lectures and lecturers, album of pictures, and other events
http://chalonge.obspm.fr

END

THANK YOU FOR YOUR ATTENTION