The Thomas-Fermi Galaxy Theory in Agreement with Observations

New Results

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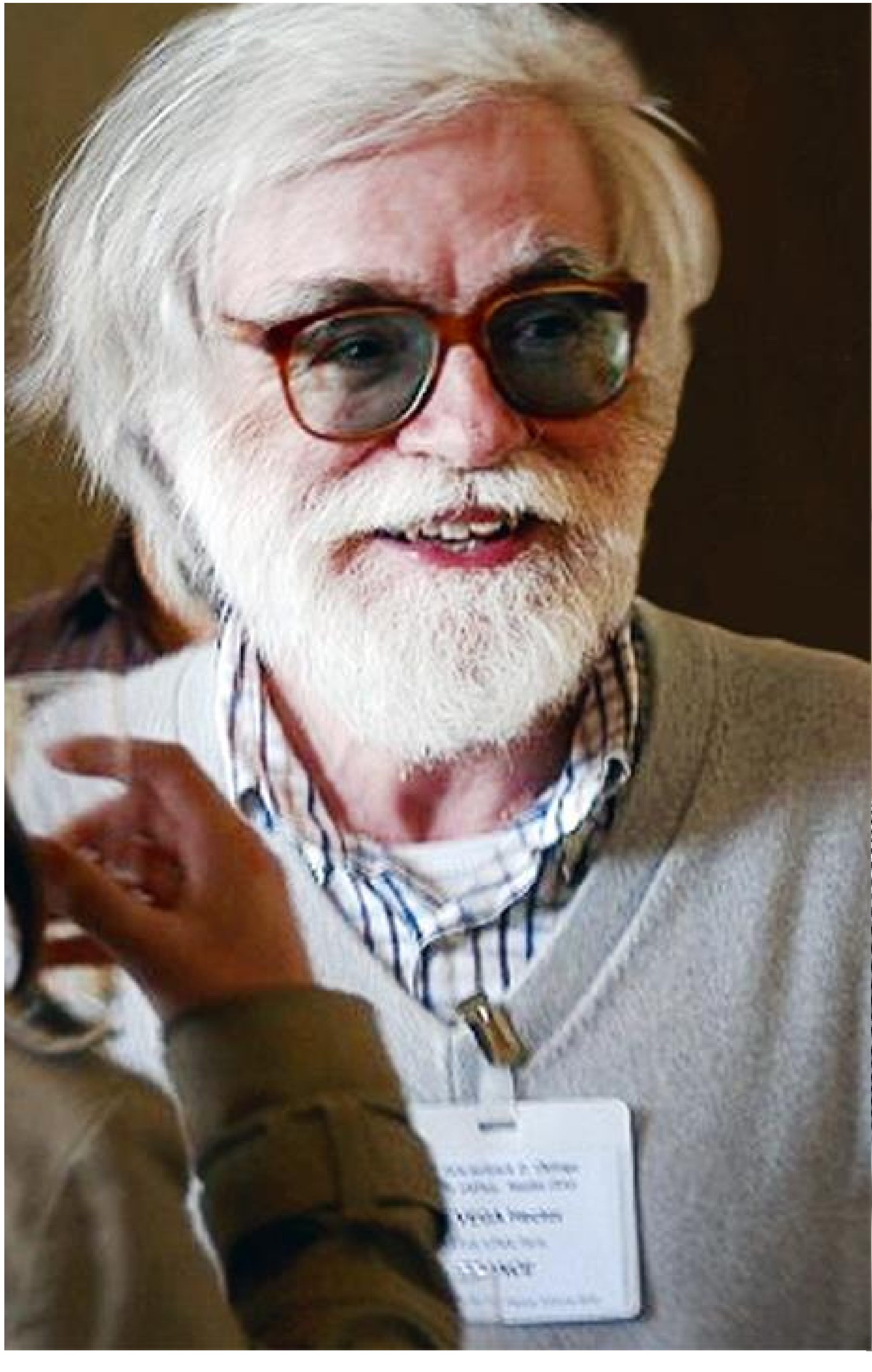
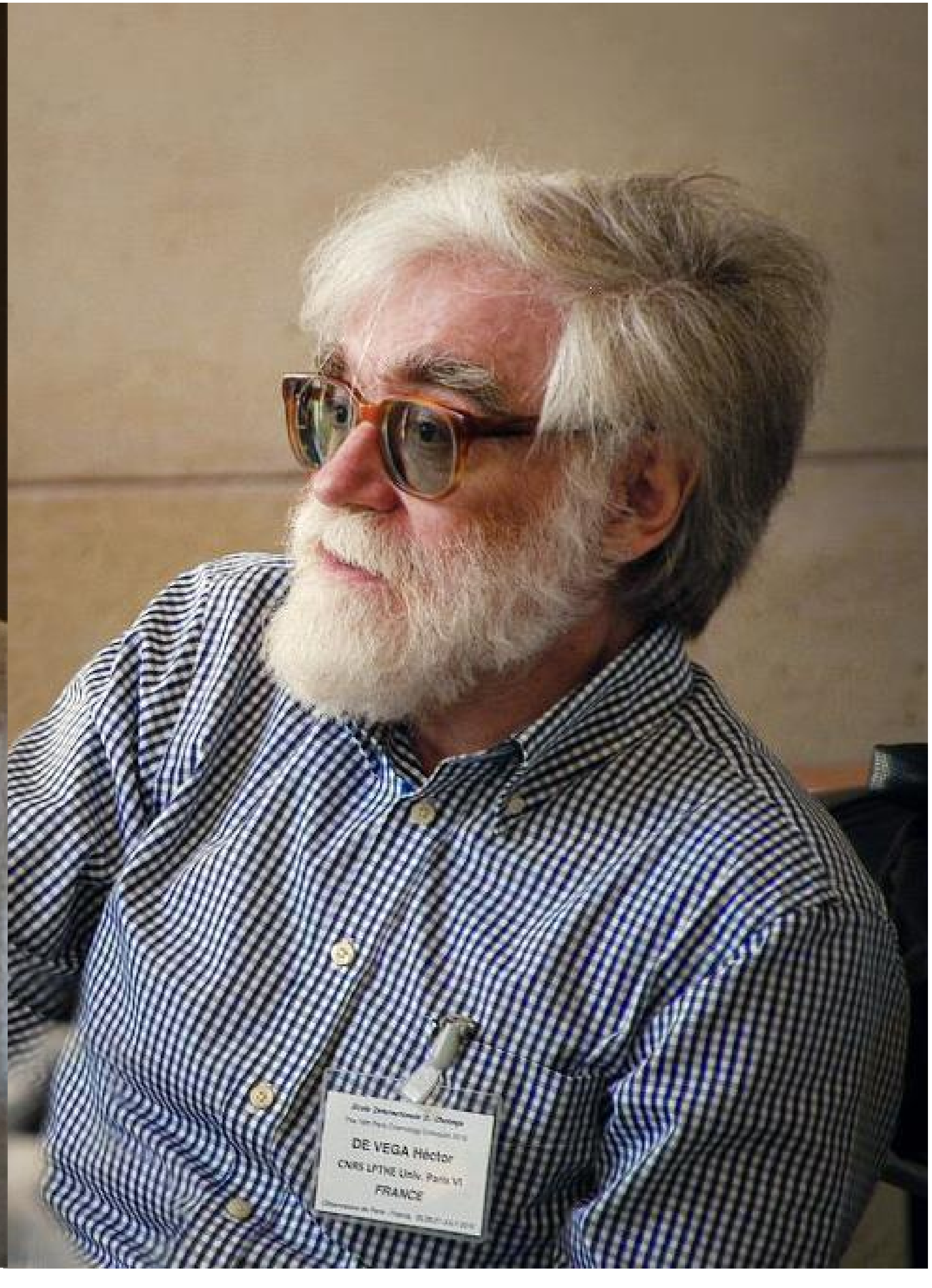
Chalonge Meudon Workshop 2015

Meudon CIAS 10-12 JUNE 2015




DE VEGA Héctor
CNRS LPTHE Univ. Paris VI
FRANCE

LA SCIENCE QUI DONNE ENVIE. UNE GRANDE AVENTURE SCIENTIFIQUE ET HUMAINE
SCIENCE WITH GREAT INTELLECTUAL ENDEAVOUR AND A HUMAN FACE

Newton, Fermi et Dirac réunis dans les galaxies par la matière noire tiède (keV)

PROGRAMME OF THE YEAR 2015

24 YEARS OF ACTIVITY. CALLING FOR UNDERSTANDING

26 MARCH 2015 : Opening Session 2015. Session ouverte de Culture Scientifique "Présentation du Programme 2015 et des Dernières Nouvelles de l'Univers". Observatoire de Paris, Bâtiment Perrault

21 MAY 2015 : Spring Open Session of Scientific Culture 2015. Session Ouverte de Printemps de Culture Scientifique Interdisciplinaire 2015 : " L'Homme et l'Univers". Observatoire de Paris, Bâtiment Perrault

9-12 JUNE 2015 : Chalonge Meudon Workshop 2015 "WDM Cosmology : from large to small scale structures in agreement with observations: galaxies, black holes, Neutrinos and Sterile Neutrinos". Observatoire de Paris, Château de Meudon-CIAS, Meudon

21-24 JULY 2015 : The 19th Paris Cosmology Colloquium Chalonge 2015: "Latest News from the Universe: WDM Cosmology, CMB, Dark Matter,Dark Energy, Neutrinos and Sterile Neutrinos". Observatoire de Paris, Bâtiment Perrault

24 JULY 2015 : Summer Open Session of Scientific Culture 2015. Session Ouverte d'Eté de Culture Scientifique 2015 : A Surprise Session

AUTOMME 2015 : Cycle Les grandes questions posées aujourd'hui à la Science: Où va la Science ? L'Exemple de la Matière Noire. Cité Internationale Univ. de Paris

16-17 OCTOBRE 2015 : Chalonge Turin Session 2015 "Latest News from the Universe, Dark Matter Galaxies and Particle Physics". Palazzo Lascaris & Accademia delle Scienze, Piamonte Région, Turin, Italy

26-27 NOVEMBER 2015 : Concluding Session 2015 & Avant-Première 2016

Par E. Vergnaud & J. Berthier

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A Laboratory of Ideas

Research, Training, Scientific Culture

A beacon pioneering and developping research, projects and training. The programme offers unvaluable 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, observers. Advanced students, post-docs, young researchers are encouradged to participate. The programme includes scientific culture events with the latest results and exhibitions.

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The Chalonge 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 24 years school history

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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)
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And other Events
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Basement- ground Zero

Dark matter is the dominant component of Galaxies and is an essential ingredient to understand Galaxy properties and Galaxy formation

Dark matter and Galaxy Formation must be treated in an cosmological context

The nature (the type) of Dark Matter and the cosmological model need to be explicitated when discussing galaxies and galaxy formation

All the building of galaxy formation depends on

the nature of Dark Matter

CONTENTS

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.

-> NEW: 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. DdVS (New Astronomy 2013) dVS PRD 2013, dVSS MNRAS to appear, dVS 2014

-> 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-

- Å **Well established sets of 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 Physics 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.

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

- Å **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.**
- Å **Smoothing the density profile at the central regions has an effect on the whole galaxy halo.**

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.

WDM THEORY OF GALAXIES
REPRODUCES THE OBSERVED GALAXY STRUCTURES
Gravity and Quantum Mechanics meet together in Galaxies

de Vega, Salucci, Sanchez MNRS 2014 reproduced the main observed properties of galaxies of all types, masses and sizes, as the rotation curves, density profiles, phase space density, and scaling relations between the galaxy masses, sizes and velocities, with a physical theory to galaxy structure which captures the essential ingredients of galaxies: **dark matter and gravity.**

Newton, Fermi and Dirac, meet together in Galaxies through Warm Dark Matter

This new framework **requires dark matter particles to be fermionic** with mass in the scale of thousands electron Volts (**keV "warm dark matter")** and described by their quantum mechanical properties, as their quantum pressure resulting from the combination of the Pauli exclusion principle and the Heisenberg uncertainty principle. Compact dwarf galaxies are thus near the Fermi gas degenerate regime, while large dilute galaxies are in the classical gas Boltzmann regime.

This approach corresponds to the Schrödinger equation in the large number of particles regime **and is for galaxies the analogue of the Thomas-Fermi approach for atoms, with gravitation instead of the electric potential**.

Universal rotation curves and Universal density profiles: The same for all galaxies

The theoretically obtained galaxy rotation curves and density profiles reproduce extremely well the observational curves from ten different and independent sets of data for galaxy masses from 5×10^{9} solar masses untill 5×10^{11} solar masses.

Remarkably enough, the normalized theoretical circular velocities and density profiles are universal (URC): they are the same for all galaxies of different types, sizes and masses, and they agree extremely well with the observational curves described by cored profiles (flat smooth profiles at the center) and their sizes.

Interestingly enough, small deviations from the exact scaling relations show up for compact dwarf galaxies as a manifestation of the quantum macroscopic effects present in these galaxies.

Robust Results

Results of this work are independent of any particular warm dark matter particle physics model, they only follow from the self-gravitation of the warm dark matter particles and their fermionic nature. These important results show the ability of this approach to describe the galaxy structures. They also show that baryonic corrections are not very important to warm dark matter, consistent with the fact that dark matter is in average at least six times more abundant than baryons. The fraction of dark matter over the total mass of galaxies goes from the 95% for large dilute galaxies till 99.99% for dwarf compact galaxies. The baryon fraction in large galaxies can only reach values up to 5 %.

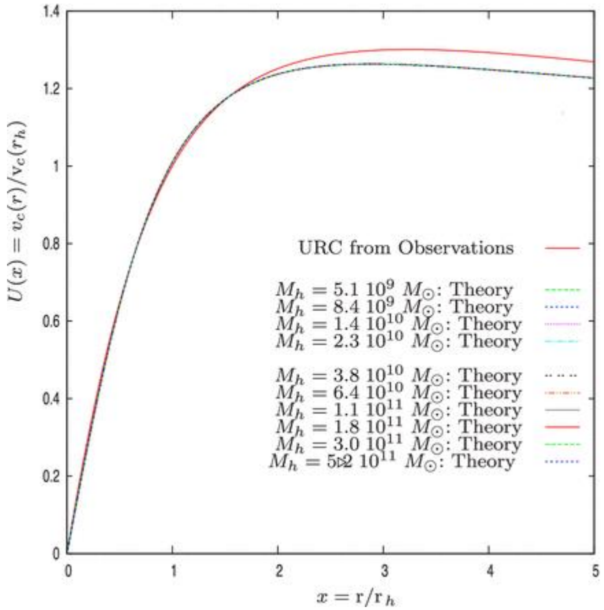
Reference:

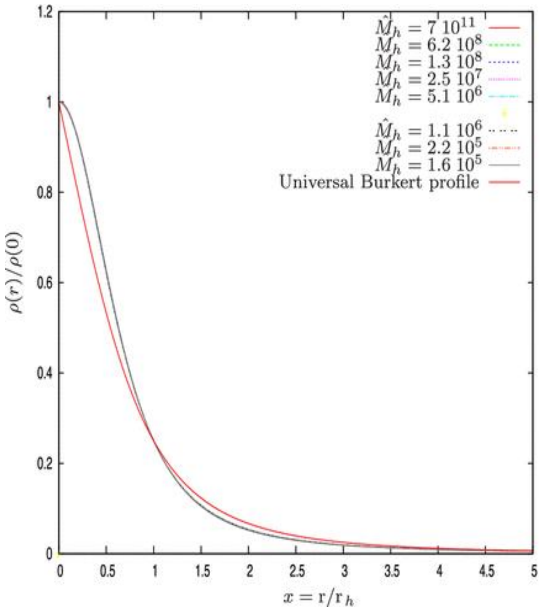
H. J. de Vega; P. Salucci; N. G.Sanchez MNRAS 442 (2): 2717-2727 (2014)

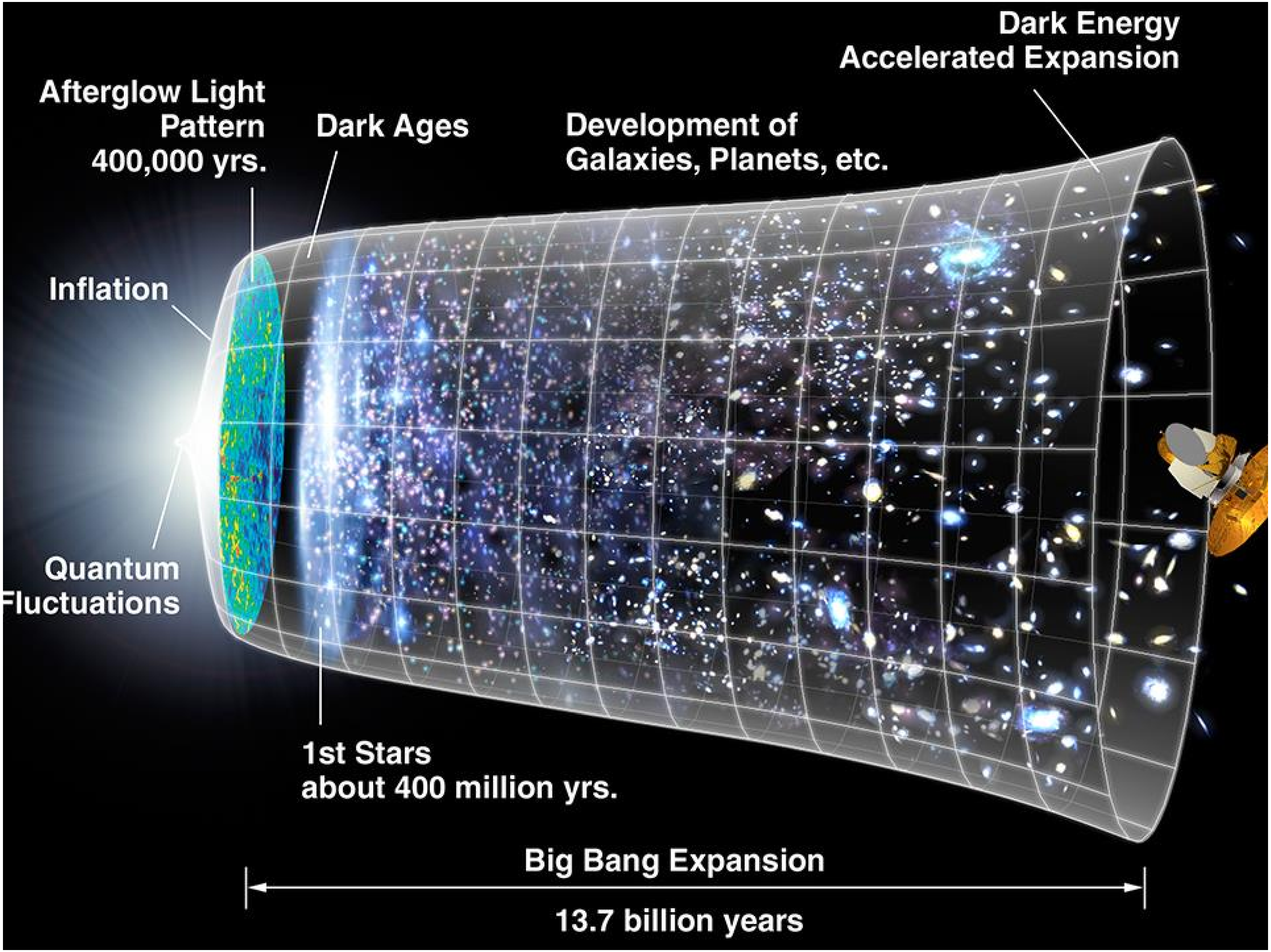
Newton, Fermi and Dirac, meet together in Galaxies through keV Warm Dark Matter

Rotation curves (left panel): The theoretical curves for 10 different galaxy masses all fall one into each other providing an Universal Rotation Curve (URC) which remarkably coincides with the observed universal curve (displayed in red) . Small deviations show up only at distances outside twice the *radius.*

The right panel shows the density profiles for the 10 galaxy masses: All fall into the same and universal density profile which reproduces the observed universal density profile and its size (in red). Interestingly enough, small deviations show up for compact dwarf galaxies as a manifestation of the quantum macroscopic effects predicted in these galaxies, and which can be further tested by next observations. (Examples of other macroscopic objects in nature are dwarf stars, neutron stars and the liquid Helium 3).






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

UPDATE and CLARIFICATIONS

LCDM agrees with CMB + LSS BUT NOT with SSS (GALAXIES)

LWDM agrees with CMB + LSS + SSS (GALAXIES)

The Standard Model of the Universe is LWDM
GR, Newtonian Gravity , FT, QFT

Sentences like « CMB confirms the LCDM model é »
Must be completed by : « in large scalesò » or updated:
CMB confirms the LWDM model in large scales

NEW: Gravity and Quantum Mechanics in Galaxies
Newton, Fermi and Dirac meet together in Galaxies because of keV WDM

2015 DARK MATTER UPDATE

Å **THERE IS NO CUSP/CORE problem:**

Å **Observed Galaxy profiles are cored.**

Å **WDM Galaxy density profiles are cored**

Å **THERE IS NO satellite problem**

Å **WDM abundance of structures agrees with observations**

Å **In addition, these are not fundamental problems.**

NO DM WIMPS, NO DM annhilation,

NO DM axions. NO DM bosons

From WMAP9 to Planck

Understanding the direction in which data are pointing:

ÅPREDICTIONS for Planck

Å Standard Model of the Universe

Å Standard Single field Inflation

Å NO RUNNING of the Primordial Spectral Index

Å NO Primordial NON GAUSSIANITY

Å N_{eff} neutrinos : --> Besides meV active neutrinos:

Å 1 or 2 sterile neutrinos

Å Would opens the sterile neutrino Family:

Å keV sterile neutrino ï WDM-

ÅLarge Hadron Collider

- The first LHC results at 7-8 TeV, with the discovery of the 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.

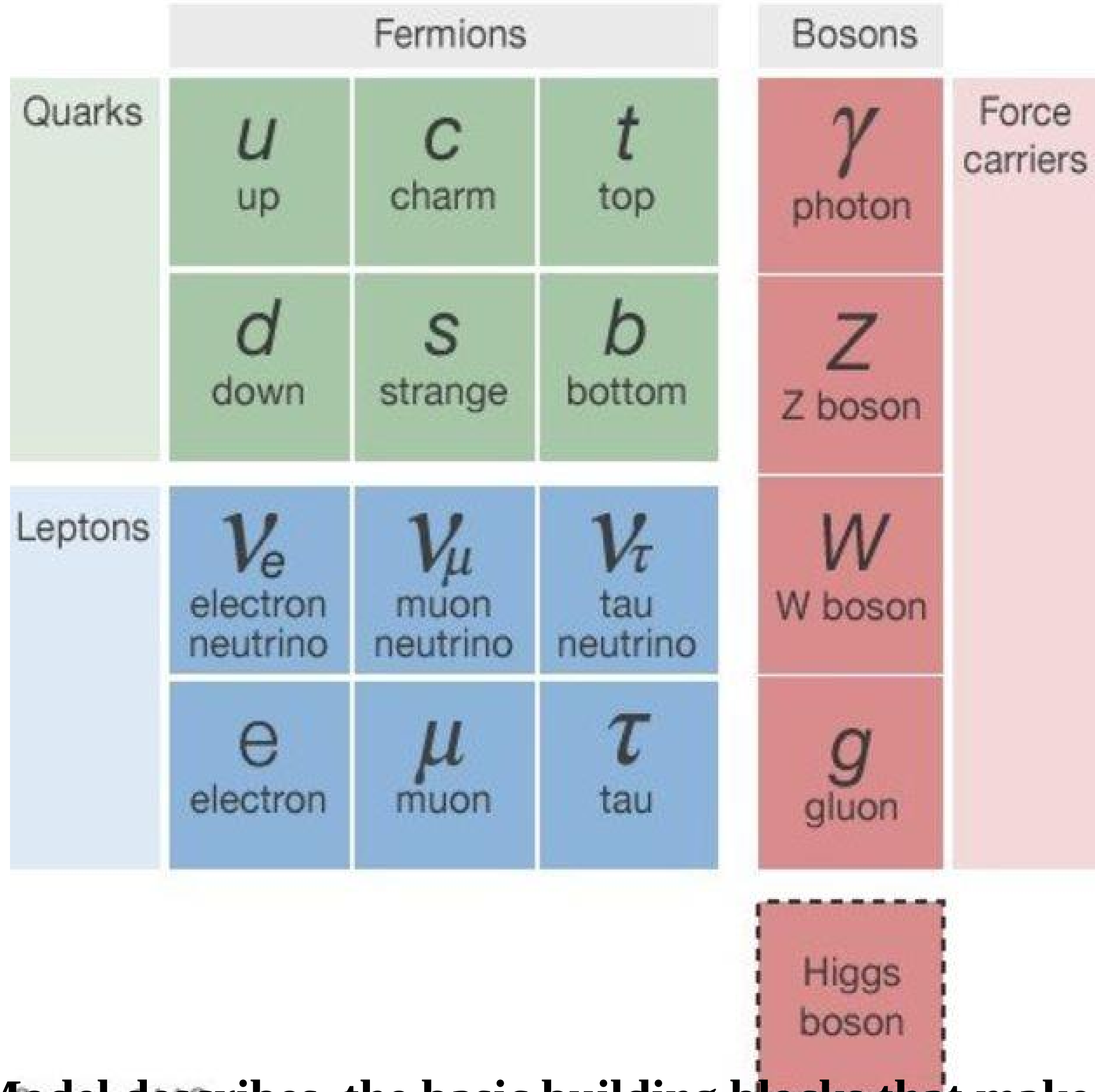
No evidence of SUSY at LHC

ñSupersymmetry 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 wimpôs signal) **ñSo far researchers who are racing to find evidence of so called "new physics", ie non-standard models, have run into a series of dead endsò.**



The Standard Model describes the basic building blocks that make up atoms and the forces of nature . Is very successful but It is not complete

What next for the LHC?

APRIL 2015: **The Large Hadron Collider (LHC) has been**
Et cela recommanceé .restarted after a two-year shutdown.

Searching Beyond the Standard Model of Particle Physics

PREDICTIONS :

NO Dark Matter at LHC

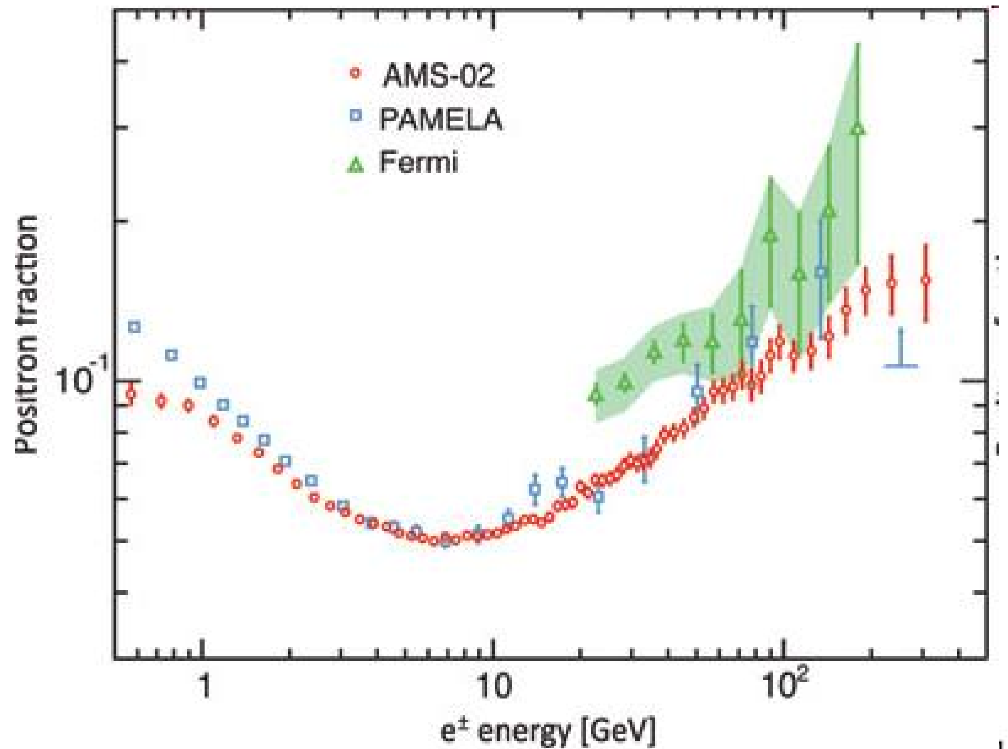
NO SUSY at LHC

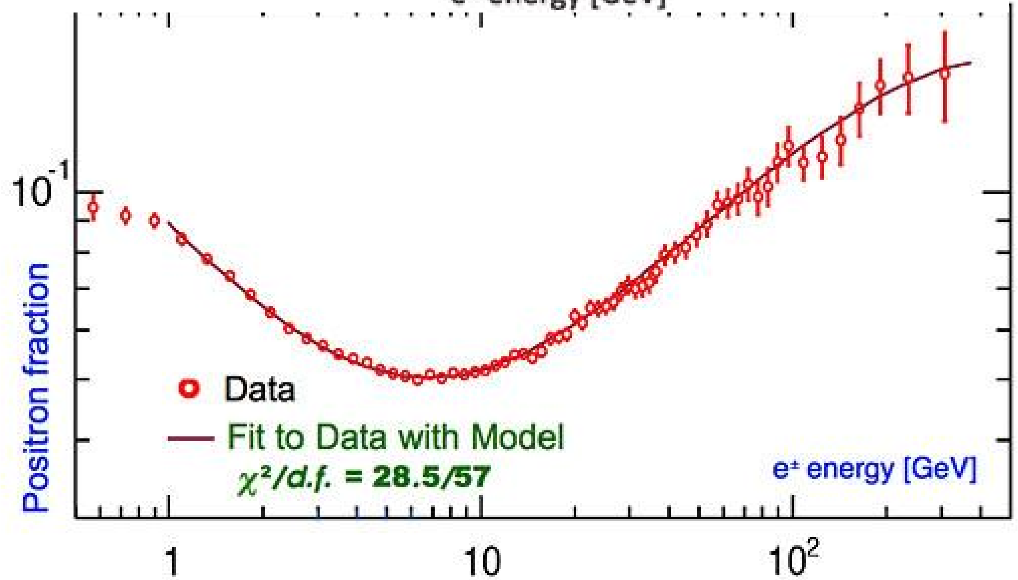
NO Extra-dimensions at LHC

NO Black Holes at LHC

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

Planck and Dark Matter, Dec2014,2015

DM annihilation est absente: OK. Sur cet aspect, les données ne laissent pas d'ambigüité possible: Souvenez-vous:

Depuis plusieurs années nous avons toujours prédit, dit, et redit qu'il nóy a pas de DM annihilation importante et que le positron excès (Pamela, FERMI, AMS-02, etc.) n'est pas du a DM annihilation mais

aux sources/ phénomènes astrophysiques: c'est dans nos slides., voir Programme 2014 chalonge par exemple http://chalonge.obspm.fr/Programme2014.html**Et ceci est de plus, un autre résultat négatif**

pour les modèles DM des Wimps, comme nous l'avons toujours dit.

ÅWhy No Experimental Detection of the DM particle has been reached so far ?

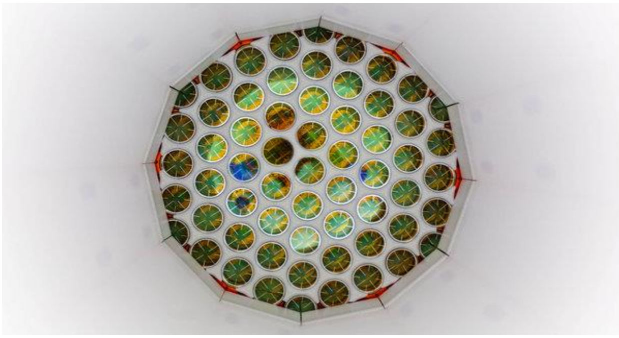
Because:

- Å All experimental searches for DM particles are dedicated to CDM: wimps of m > 1 GeV,
- Å While the DM particle mass is in the keV scale .
- Å Moreover, past, present and future reports of signals of such CDM experiments cannot be due to DM because of the same reason.
- Å The inconclusive signals in such experiments should be originated by phenomena of other kinds.
- Å 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

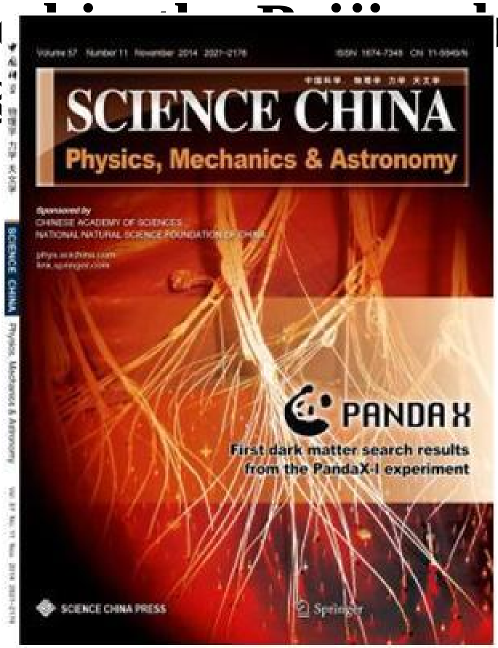


- **They found no sign of WIMPS signals.** beyond the expected background noise.
- The experiment did so at far better sensitivities than any such experiment before it.

ÅFirst dark matter search results from Chinese underground lab hosting

ÅPandaX-I experiment

Å 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 

ased journal *Science China Physics, Mechanics &*

Å NEGATIVE RESULTS

Å for Wimps

Å China Science Press

Å 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 Editorsô Suggestion.**

NEGATIVE RESULTS for WIMPS

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

What next for the LHC?

APRIL 2015: **The Large Hadron Collider (LHC) has been restarted after a two-year shutdown. Et cela recommanceé .Searching Beyond the Standard Model of Particle Physics**

PREDICTIONS:

NO Dark Matter at LHC

NO SUSY at LHC

NO Extra-dimensions at LHC

NO Black Holes at LHC

Sterile neutrinos and CMB fluctuations

CMB data give the effective number of neutrinos, $N_{\rm eff}$.
$N_{\rm eff}$ is related in a subtle way to the number of active neutrinos (3) plus the number of sterile neutrinos.
Planck result: $N_{\rm eff} = 3.5 \pm 0.5$ (95%;P+WP+highL+H_0+BAO)

Entropy conservation determines the contributions to $N_{\rm eff}$.
WDM sterile neutrino contribution at recombination
$\Delta N^{WDM} = \left(\frac{T_d}{T_{rc}}\right)^4 = \left[\frac{g_{rc}}{g(T_d)}\right]^{4/3}$. At recombination $g_{rc} = 29/4$.
WDM decouples early at T_d beyond the Fermi scale
The number of UR degrees of freedom at decoupling $g(T_d)$ includes all SM particles and probably beyond.
$g_{SM} = 427/4 \quad , \quad g_{MSSM} = 915/4,$
$\Delta N^{WDM}_{SM} = 0.02771\ldots \quad , \quad \Delta N^{WDM}_{MSSM} = 0.01003\ldots$
Too small to be measurable at present !
Conclusion: Planck results say nothing about WDM.
Besides, Planck results are **compatible** with one or two eV sterile neutrinos (see e. g. G. Steigman, 1303.0049).

Recent News on Cosmological Observables

Before 2013: Hubble constant $H_0 = 73.8 \pm 2.4 \, \frac{\mathrm{km}}{\mathrm{s}} \, \frac{1}{\mathrm{Mpc}}$ 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: $H_0 = 67.3 \pm 1.2 \, \frac{\mathrm{km}}{\mathrm{s}} \, \frac{1}{\mathrm{Mpc}}$. $\Omega_m = 0.32 \pm 0.02$.

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:

$H_0 = 70 \pm 1.2 \, \frac{\mathrm{km}}{\mathrm{s}} \, \frac{1}{\mathrm{Mpc}}$. $\Omega_m = 0.30 \pm 0.01$ 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,

Planck and the cosmological parameters

La valeur Neff est très importante et corrélée aux autres paramètres cosmologiques.

Planck a refait l'analyse des données 2014/2015 avec les mêmes priors (a priori) que en 2013 : ils ont donc très peu des corrections aux paramètres cosmologiques par rapport a Planck 2013 et donc ils ont un Neff compatible avec 3 neutrinos et les mêmes problèmes 2013 pour H_0 , pour la proportion de dark énergie et pour the dark matter proportion, pour sigma_8, etc. , car ils sont tous corrèles

Trop haute oméga DM (of about 26-27 %) , une trop basse oméga lambda (68%) et une trop basse H_0 pour n'arriver qu'a Neff compatible avec 3 neutrinos.... et donc ils ont les mêmes quôavant.

Planck and Neutrinos

- **At early times:** CMB sensitive to radiation The radiation density other than photons is described by the **parameter Neff:** rad = C(Neff) photons.
- **At late times:** CMB sensitive to neutrino masses

- **The Priors in the Planck analyse:**
- **Standard value for Neff= 3.046, 3 active neutrinos**
- **Σ mν = 0.06 eV (1 massive, the other massless)**

- **This is the source of the conflict with the values of H0 , lensing and clusters (sigma8)**

Planck and Neutrinos. 2

Å **Une analyse plus fine que celle fait par Planck sur les données Planck 2013 a été faite par plusieurs groups différents et donne Neff compatible avec 4 neutrinos = les 3 actifs connus + 1 stérile et les paramètres cosmologiques sans tensions avec les autres observations .**

Å

Donc, les données Planck 2014 pourront être a nouveau ré-analyses par d'autres teams et Neff et les valeurs des paramètres cosmologiques corrigés.

Planck and Neutrinos.3

- Å →En fait le **CMB** est sensible à la valeur de sigma8 très tôt dans l'Univers, **à redshift =1100** (moment où l'Univers devient transparent **380 000 après le Big Bang**), **alors que les amas qui se forment tard, mesurent la valeur de sigma8 à z~1 (il y a 8 milliards d'années).**
- Å →La relation entre ces deux valeurs dépend de la croissance des structures. **Or celle-ci est ralentie par les neutrinos**, d'autant plus qu'ils sont massifs. Dans le modèle standard de la cosmologie, la somme des masses des neutrinos est aujourd'hui fixée à une valeur minimale de 0.06 eV (correspondant à la mesure de la somme des masses d'oscillation déterminée par les expériences de neutrinos et en considérant que la masse du **neutrino** le plus léger est nul).
- Å →**Le désaccord** sur sigma8 **entre le CMB et amas peut être résolu** si on permet que la somme des masses des neutrinos soit comprise entre **0.2 et 0.3 eV.** Cependant, cette valeur haute doit être confrontée aux contraintes posées par les BAO et l'analyse des forêts Lymann-

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....

Detection of a 3.56 keV X-ray line in galaxy clusters

E.Bulbul et al. ApJ 789, 23 (2014) reported the detection of a new X-ray line in galaxy clusters that may be originated by the decay of a 7.1 keV sterile neutrino.
Sterile neutrinos remain out of thermal equilibrium today.

From the conversion formulas, a 7.1 keV DW sterile neutrino behaves as a 1.99 keV thermal relic and a 7.1 keV SF sterile neutrino behaves as a 2.8 keV thermal relic.

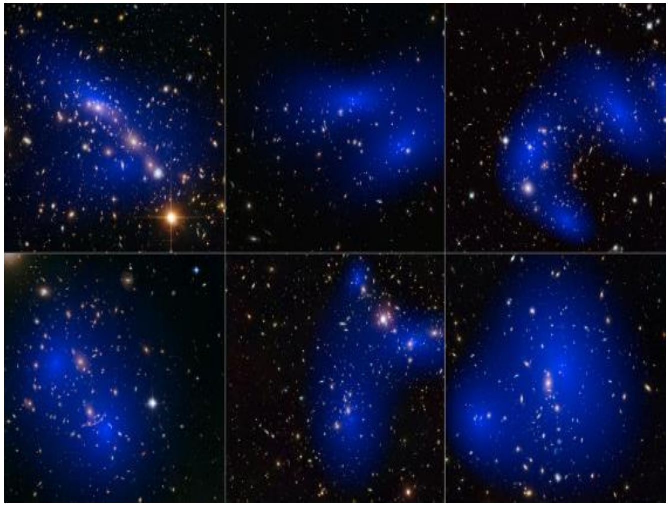
Besides, a 7.1 keV SF sterile neutrino with lepton asymmetry yields similar results (K Abazajian, 2014).

WDM thermal relics with thermal mass near 2 keV provide correct small scale structure formation.

Therefore, a 7.1 keV sterile neutrino may be the dark matter particle.

Confirmation of the detection and identification of the 3.56 keV X-ray line from Astro-H is awaited for 2015 !

Dark matter even darker than once thought



Hubble & Chandra show that dark matter interacts with itself even less than previously thought, and narrow down the options for what dark matter might be.

Self-interacting dark matter becames disfavored

Good News for WDM

(Les options a CDM:

WDM and self-interacting DM)

The non-gravitational interactions of dark matter in colliding galaxy clusters

David Harvey, Richard Massey, Thomas Kitching, Andy Taylor, Eric Tittley

Science, 27 March 2015

Collisions between galaxy clusters provide a test of the non-gravitational forces acting on dark matter.

Previously: Dark matterôs lack of deceleration in the ôbullet cluster collisionô constrained its Self-interaction cross-section DM/m < 1.25 cm2/g (68% CL)

Using the Chandra and Hubble Space Telescopes 72 collisions have now been observed. Combining these measurements statistically, imply :

1. The existence of dark mass at 7.6 sigma significance.

2. Self-interaction cross-section DM/m < 0.47 cm2=g (95% CL) → disfavoring the proposed extensions to the standard model: self-interacting DM

30 systems, mostly between redshift $0.2 < z < 0.6$
plus two at $z > 0.8$,
containing 72 pieces of structure in total

EXISTENCE of DARK MATTER is Reaffirmed:

Observations that do not presuppose the existence of dark matter show that

clusters of galaxies with 10^{14} Msun

contain only 3.2% of their mass
in the form of stars.

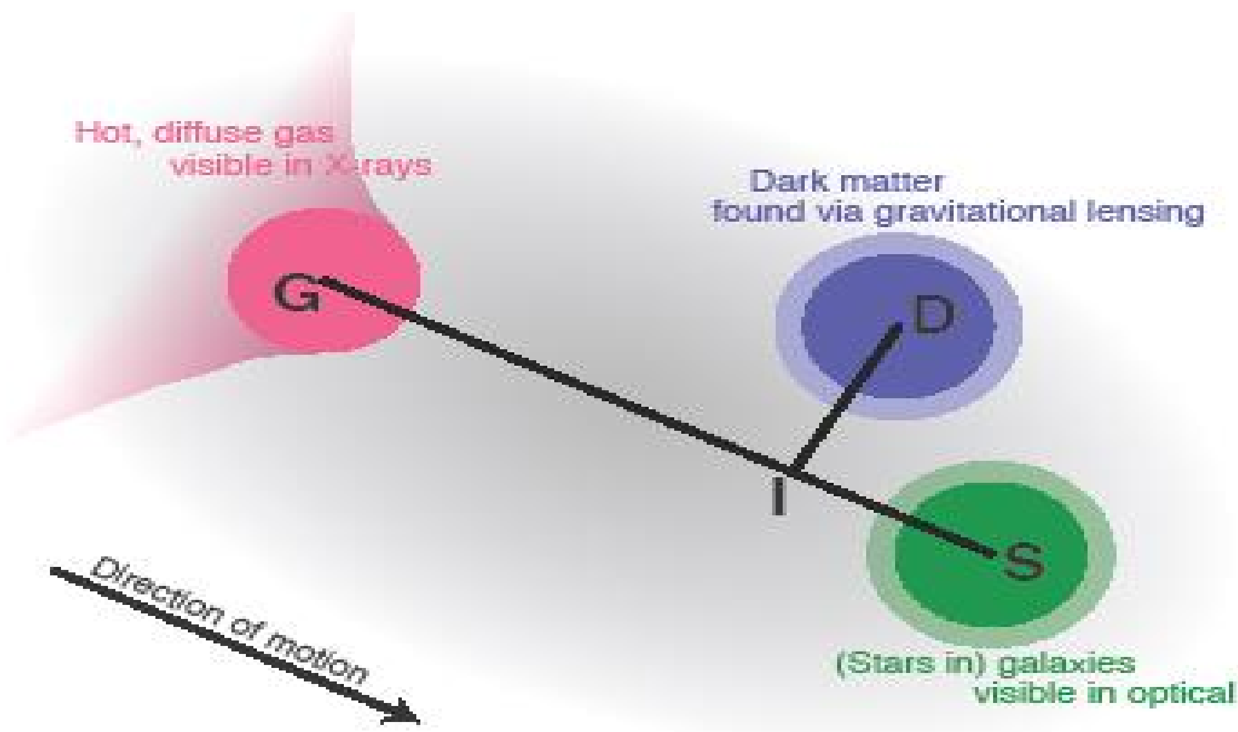
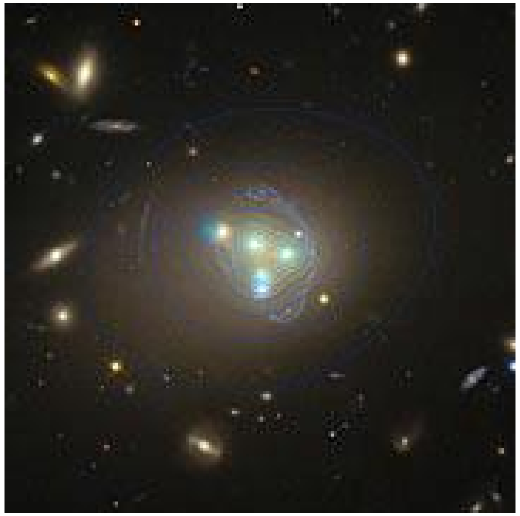


Figure 1: Cartoon showing the three components in each piece of substructure, and their relative offsets, illustrated by black lines. The three components remain within a common gravitational potential, but their centroids become offset due to the different forces acting on them, plus measurement noise. We assume the direction of motion to be defined by the vector from the diffuse, mainly hydrogen gas (which is stripped by ram pressure) to the galaxies (for which interaction is a rare event). We then measure the lag from the galaxies to the gas δ_{SG}, and to the dark matter in a parallel δ_{SI} and perpendicular δ_{DI} direction.



Le suivi d'une collision galactique au moyen du Très Grand Télescope de l'ESO et du Télescope Spatial Hubble du consortium NASA/ESA a permis de collecter des informations sur la matière noire.

En combinant les données duVLT de l'ESO au Chili aux images acquises par le télescope spatial Hubble, la collision simultanée de quatre galaxies au sein de l'amas Abell 3827 a été étudiée.

Elle a notamment été en mesure de localiser la matière contenue au sein de ce système et de comparer la distribution de matière noire aux positions occupées par les galaxies lumineuses.

A SUIVREé .

The equation of state of galaxies

We have derived the equation of state of galaxies, that is the relation between pressure and density, and provided its analytic expression : $P(r) = V^2(r)\ \rho(r)$

Two regimes for galaxies emerge :

(i) Large dilute galaxies for M_h> 2,3 10^6 Msun and effective températures T_0> 0,017 K described by the classical Boltzmann gaz selfgravitational with local ideal gaz equation of state at each point (r-dependent).

(ii) Compact dwarf galaxies for 1,6 10 ^ 6 Msun > M_h> M_ {h, min} = 30000 (2keV / m) ^ {16/5} Msun, T_0 <0,011 K described by the fermion WDM quantum regime with an equation of state more xxx raide near (but not at) the degenerate state. In particular, the denerated limit T_0 = or extreme quantum limit yields the more compact and smallest galaxy. Moreover, in the dilute regime: the halo radius r_h the v2 and the temperature T_0 show scaling laws in terms of M_h. The amplitudes of these analytic scaling laws have proche, mais pas exactement à l'état dégénéré).

→ **The normalized density and velocity profiles are universal fonctions of r / r_h. Thus, the scaling laws and the universality appearing in the dilute classical regime of large galaxies are linked to the ideal gaz behaviour of WDM in this regime.**

→**These results and the theoretical rotation courves remarquably reproduce for r <r_h the galaxy observations.**

→**In the compact regime of small galaxies the equation of state depends on the mass of each galaxy, the density and velocity profiles are not anymore universal , this reflects the quantum physics of the WDM fermions in the compact regime (which generically are near but not at exactly the degenerate limit-state).**

The Distribution Function of Dark Matter

→ We developped inverse methods allowing to determine the distribution function f(E) from the real density profiles obtained from observations or from numerical simulations:

→ Thus, we have found the distribution function f (E) of galaxy DM halos and the corresponding equation of state from the DM observed density profiles .

→ That is to say, we have solved for galaxies the analogue of the integral Eddington equation of the gaz of stars in globular clusters . The observed density profiles are a realistic starting point, thus the f(E) obtained from them are realistic fonctions .

NEW RESULTS

(i) CORED density profiles produce distribution functions which are finite and positives at the center , while cusped density profiles with "cusps" growing as 1/r or more, always produce distribution functions which are divergent at the center.

(ii) The observed CORED density profiles produce distribution functions which are very near the THERMAL Boltzmann distributions for r <3 r_h . (r_h being the halo radius).

(iii) The analytic expresions for the dispersion velocity and the pressure are derived, they verify the ideal gaz equation of state for the DM with a local temperature T(r) = mv^2 (r) / 3.

T (r) is slowly variable and turns out to be constant in the same

(iv) The DM halos can be consistently considered as being in Local Thermal Equilibrium with a temperature

$T(r) = T_0$ constant for $r < 3\, r_h$,

and $T(r) = m v^2(r) / 3$

for $3\, r_h < r < R_{viriel}$,

which slowly decreases with r.

That is to say, for $r < R_{viriel}$,

the DM halo is a Self-Gravitant

Thermal Gaz without collisions.

(v) In the external halo region T(r) follows nicely the decreasing of the squared circular velocity

The DM in the halos of galaxies is thermalized

- All these results show robustly that the DM self-gravitating gaz can thermalize in despite of being collissionless:
- This is due to the gravitational interaction between the DM particles and to the fact that this is an ergodic system.
- The collisionless self-gravitating gas is an isolated system which is not integrable.
- Namely, the particle trajectories explore ergodically the constant energy manifold in phase-space, covering it uniformly according to precisely the microcanonical measure and yielding to a thermal situation

- **Physically, these phenomena are clearly understood :**
- **In the inner halo region the density is higher than beyond the halo radius.**

  The gravitational interaction in the inner region is strong enough and thermalizes the self-gravitating gas of DM particles

  while beyond the halo radius the particles are too dilute to thermalize, namely, although they are virialized, they had not enough time to accomplish thermalization.

The DM in the galaxy halos is thermalized II

- Å Virialization always starts before than thermalization.
- Å In the process of thermalization there is an energy transfer flow of potential energy into kinetic energy.
- Å Clearly, in the outside halo region we find that the kinetic energy is lower than in the inside the region thermalization is already achieved.
- Å And All these results are consistent with the result found : The local temperature T(r) in the outside halo region is lower than the temperature inside the halo region where thermalisation is achieved.

WARM DARK MATTER REPRODUCE

→OBSERVED GALAXY DENSITIES AND VELOCITY DISPERSIONS

→SOLVES the OVERABUNDANCE (ñsatellite) PROBLEM

->OBSERVED SURFACE DENSITY VALUES OF DARK MATTER DOMINATED GALAXIES

→OBSERVED GALAXY CORED DENSITY PROFILES : QUANTUM MECHANICS

Å WDM OVERALL CONCLUSION

Å **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.**

Å **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.**

WDM + BARYONS

Baryons have not been included in this study. This is fully justified because on one hand dwarf compact galaxies are composed today 99.99 % of DM, and on the other hand **the baryon fraction in large galaxies can reach values up to 1 - 3 %.**

Since Fermionic WDM by itself produces galaxy main properties and structures in agreement with observations for all types of galaxies, masses and sizes, the effect of including baryons is expected to be a small correction to these pure WDM galaxy structural results, consistent with the fact that dark matter is in average six times more abundant than baryons.

Å *Science is built up with facts,*

Å *as a house is with stones.*

Å *But a collection of facts is no more a science*

Å *than a heap of stones is a house.*

-- Henri Poincaré

Å *La science est construit avec des faits,*

Å *ainsi comme une maison est construite*

Å *avec des pierres.*

Å *Mais une collection de faits nõest pas une science, ainsi comme un tas de pierres nõest pas une maison.*

END

THANK YOU FOR YOUR ATTENTION