Física del Universo

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IFLP-UNLP-CONICET, La Plata

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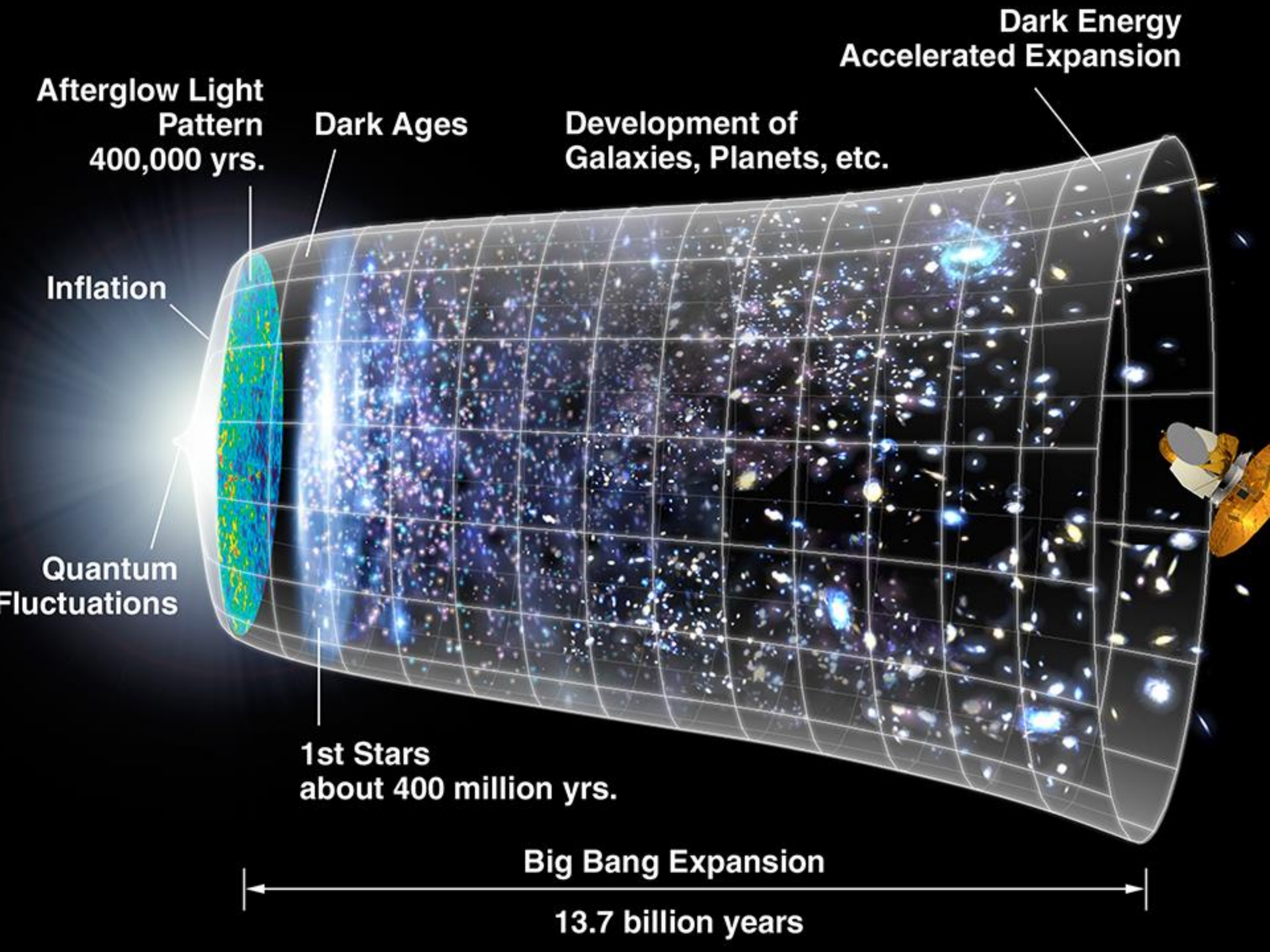


Dark Energy
Accelerated Expansion
Afterglow Light
Pattern
400,000 yrs.
Dark Ages
Development of
Galaxies, Planets, etc.
Inflation
Quantum
Fluctuations
1st Stars
about 400 million yrs.
Big Bang Expansion
13.7 billion years

THE HISTORY OF THE UNIVERSE IS A HISTORY of EXPANSION and COOLING DOWN

THE EXPANSION OF THE UNIVERSE IS THE MOST POWERFUL REFRIGERATOR

INFLATION PRODUCES THE MOST POWERFUL STRETCHING OF LENGTHS

THE EVOLUTION OF THE UNIVERSE IS FROM QUANTUM TO SEMICLASSICAL TO CLASSICAL

From Very Quantum (Quantum Gravity) state to Semiclassical Gravity (Inflation) stage (Accelerated Expansion) to Classical Radiation dominated Era followed by Matter dominated Era (Deccelerated expansion) to Today Era (again Accelerated Expansion)

THE EXPANSION CLASSICALIZES THE UNIVERSE

THE EXPANSION OF THE UNIVERSE IS THE MOST POWERFUL QUANTUM DECOHERENCE MECHANISM

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.

Cooling: temperature decreases as lenghts increase.

The expansion of the Universe started explosively fast: the Big Bang !! The Big Bang has no center. The Universe expands similarly at all space points. Homogeneous and isotropic expansion at all times.

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

Universe homogeneous and isotropic during 80 Myr. Since then, structures (galaxies) form via dynamical gravitational processes.

Inflation and subsequent eras of the Universe

Main Events since the Big Bang	Time from beginning	Tempe-rature	Expansion since B B
Inflation - DED	10^{-36} sec	10^{29} K	10^{28}
Protons & neutrons form - RD	10^{-5} sec	10^{12} K	10^{45}
D, He, Li form - RD	20 sec	10^{9} K	10^{48}
Non-relativistic ($v \ll c$) particles dominate - MD	57000 yr	8000 K	3×10^{53}
Atoms and CMB form	370000 yr	3000 K	10^{54}
Galaxies and Stars start to form - MD	80 Myr	90 K	10^{55}
Today - DED	13.7 Gyr	3 K	10^{57}

ED: DE dominated, RD: radiation dom, MD, matter dom.

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

Standard Cosmological Model:

Ordinary Matter + Dark Matter + Cosmological Constant

- Begins by the inflationary era.
- Gravity is described by Einstein's General Relativity. Matter determines the spacetime geometry.
- Ordinary Matter described by the Standard Model of Particle Physics: $SU(3) \otimes SU(2) \otimes U(1) =$ qcd+electroweak model. Strong, electromagnetic and weak interactions involving quarks, gluons, protons, electrons, photons and neutrinos.
- Dark matter plays a crucial role in galaxy and structures formation. DM could be a sterile neutrino which does not interact through the SM and has mass $\sim$ keV.
- Dark energy uniformly distributed in space. Repulsive gravitational force. Described by the cosmological constant Λ.

Standard Cosmological Model: Concordance Model

$ds^2 = dt^2 - a^2(t)\, d\vec{x}^{\,2}$: spatially flat geometry.

The Universe starts by an **INFLATIONARY ERA**.

Inflation = Accelerated Expansion: $\frac{d^2a}{dt^2} > 0$.

During inflation the universe expands by at least sixty efolds: $e^{62} \simeq 10^{27}$. Inflation lasts $\simeq 10^{-36}$ sec and ends by $z \sim 10^{29}$ followed by a radiation dominated era.

Energy scale when inflation starts $\sim 10^{16}$ GeV ($\Longleftarrow$ CMB anisotropies) which **coincides** with the GUT scale.

Matter can be effectively described during inflation by a Scalar Field $\phi(t, x)$: the Inflaton.

Lagrangean: $\mathcal{L} = a^3(t) \left[\frac{\dot{\phi}^2}{2} - \frac{(\nabla\phi)^2}{2\, a^2(t)} - V(\phi) \right]$.

Friedmann eq.: $H^2(t) = \frac{1}{3\, M_{Pl}^2} \left[\frac{\dot{\phi}^2}{2} + V(\phi) \right]$, $H(t) \equiv \dot{a}(t)/a(t)$

Standard Cosmological Model: ΛCDM $\Rightarrow$ ΛWDM

Dark Matter + Λ + Baryons + Radiation
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 and Age of the Universe Measurements
- Properties of Clusters of Galaxies
- Galaxy structure explained by WDM

Universe Inventory Today

The universe is spatially flat.
Curvature is present in the space-time geometry.

Today: Dark Energy (Λ): 73 % , Dark Matter: 22 %

Baryons $+$ electrons: 4.5 % , Radiation ($\gamma + \nu$): 0.0085%

83 % of the matter in the Universe is DARK.

Total average energy density today (very dilute!):

$\rho(\text{today}) = 0.947 \; 10^{-29} \; \frac{\text{g}}{\text{cm}^3} \simeq$ 5 proton masses per m^3

DM dominates in the halos of galaxies (external part).
Ordinary matter dominates around the center of galaxies.

Most galaxies exhibit a gigantic black hole in the center.
Central black hole mass ~ 0.001 galaxy mass.

Galaxies form out of matter collapse via gravitational dynamics.

The Universe Today is Essentially Empty

Inter galactic distances $\sim$ Mpc. (pc = 3.0857×10^{13} kms.)

Galaxy sizes $\sim 0.0001 - 0.1$ Mpc. (pc = 3.262 light years.)

99.9 % of the universe volume is the intergalactic space with an average energy density of 5 proton masses per m (cosmological constant).

Galaxy masses: $10^6 - 10^{12}\ M_\odot$ from dwarf compact galaxies to (diluted) big galaxies spirals.

Galaxy density:

$\sim 4000 - 40000$ proton masses per m^3 for big galaxies.

$\sim 4 \times 10^6$ proton masses per m^3 for small compact galaxie

For comparison: air density at the atmospheric pressure and 0^o C $\sim 3.9 \times 10^{26}$ proton masses per m^3.

The Fossil Cosmic Microwave background and the Primordial Gravitons

Cosmic microwave background almost homogeneous and isotropic plus small inhomogeneities $\sim 10^{-4}$.

Inflation is the only explanation for the CMB including these small fluctuations of quantum origin $\sim 10^{-4}$.

Density CMB anisotropies first detected in 1992 by COBE.

Einstein's General Relativity predicts the existence of gravitational waves. Oscillations of the space-time itself.

Primordial gravitons are produced during inflation. They appear as tensor fluctuations in the CMB anisotropies.

This detection show two important results: a) the existence of gravitational waves, b) their existence as quantized gravitons.

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 (and all on them), ...
- the CMB anisotropies today.

That is, our present universe (including ourselves) was built out of inflationary quantum fluctuations.

The Theory of Inflation

Inflation can be formulated as an effective field theory in the Ginsburg-Landau sense. Main predictions:

- The inflation energy scale turns to be the grand unification energy scale: $= 0.70 \times 10^{16}$ GeV
- The MCMC analysis of the WMAP+LSS data combined with the effective theory of inflation yields: a) the inflaton potential is a double–well, b) the ratio r of tensor to scalar fluctuations. has the lower bound: $r > 0.023$ (95% CL) , $r > 0.046$ (68% CL) with $r \simeq 0.051$ as the most probable value.

This is borderline for the Planck satellite ($\sim 12/2012?$)
Burigana et. al. arXiv:1003.6108, ApJ to appear.
D. Boyanovsky, C. Destri, H. J. de Vega, N. G. Sánchez, (review article), arXiv:0901.0549, Int.J.Mod.Phys.**A 24**, 3669-3864 (2009).

Primordial Power Spectrum

Adiabatic Scalar Perturbations: $P(k) = |\Delta_{k\;ad}^{(S)}|^2 \; k^{n_s - 1}$.

To dominant order in slow-roll:

$$|\Delta_{k\;ad}^{(S)}|^2 = \frac{N^2}{12\,\pi^2} \; \left(\frac{M}{M_{Pl}}\right)^4 \; \frac{w^3(\chi)}{w'^2(\chi)} \; .$$

Hence, for all slow-roll inflation models:

$$|\Delta_{k\;ad}^{(S)}| \sim \frac{N}{2\,\pi\sqrt{3}} \left(\frac{M}{M_{Pl}}\right)^2$$

The WMAP result: $|\Delta_{k\;ad}^{(S)}| = (0.494 \pm 0.1) \times 10^{-4}$

determines the scale of inflation M (using $N \simeq 60$)

$$\left(\frac{M}{M_{Pl}}\right)^2 = 0.85 \times 10^{-5} \;\longrightarrow\; M = 0.70 \times 10^{16} \text{ GeV}$$

The inflation energy scale turns to be the grand unification energy scale !! We find the scale of inflation without knowing the tensor/scalar ratio r !!

The scale M is independent of the shape of $w(\chi)$.

spectral index n_s, the ratio r and the running of n_s

$r \equiv$ ratio of tensor to scalar fluctuations.
tensor fluctuations = primordial gravitons.

$$n_s - 1 = -\frac{3}{N} \left[\frac{w'(\chi)}{w(\chi)}\right]^2 + \frac{2}{N} \frac{w''(\chi)}{w(\chi)} \quad , \quad r = \frac{8}{N} \left[\frac{w'(\chi)}{w(\chi)}\right]^2$$

$$\frac{dn_s}{d\ln k} = -\frac{2}{N^2} \frac{w'(\chi)\, w'''(\chi)}{w^2(\chi)} - \frac{6}{N^2} \frac{[w'(\chi)]^4}{w^4(\chi)} + \frac{8}{N^2} \frac{[w'(\chi)]^2\, w''(\chi)}{w^3(\chi)} ,$$

χ is the inflaton field at horizon exit.

$n_s - 1$ and r are always of order $1/N \sim 0.02$ (model indep.)

Running of n_s of order $1/N^2 \sim 0.0003$ (model independent).

Primordial Non-gaussianity $f_{NL} =$ order $1/N$

D. Boyanovsky, H. J. de Vega, N. G. Sanchez,
Phys. Rev. D 73, 023008 (2006), astro-ph/0507595.

MCMC Results for double–well inflaton potential

Bounds: $r > 0.023$ (95% CL) , $r > 0.046$ (68% CL)

Most probable values: $n_s \simeq 0.964,\ r \simeq 0.051 \Leftarrow$measurable!!
The most probable double–well inflaton potential has a moderate nonlinearity with the quartic coupling $y \simeq 1.26\ldots$.

The $\chi \to -\chi$ symmetry is here spontaneously broken since the absolute minimum of the potential is at $\chi \neq 0$

$$w(\chi) = \frac{y}{32}\left(\chi^2 - \frac{8}{y}\right)^2$$

MCMC analysis calls for $w''(\chi) < 0$ at horizon exit
$\Longrightarrow$ double well potential favoured.

C. Destri, H. J. de Vega, N. Sanchez, MCMC analysis of WMAP data points to broken symmetry inflaton potentials and provides a lower bound on the tensor to scalar ratio, Phys. Rev. D77, 043509 (2008), astro-ph/0703417.

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).

LOWER BOUND on r

THE PRIMORDIAL GRAVITONS

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

$$r > 0.023 \text{ at } 95\% \text{ CL and}$$

$$r > 0.046 \text{ at } 68\% \text{ CL.}$$

Moreover,we find $r = 0.051$ the most probable value

For the other cosmological parameters, both analysis agree.

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

Two key observable numbers :

associated to the primordial density and primordial gravitons :

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

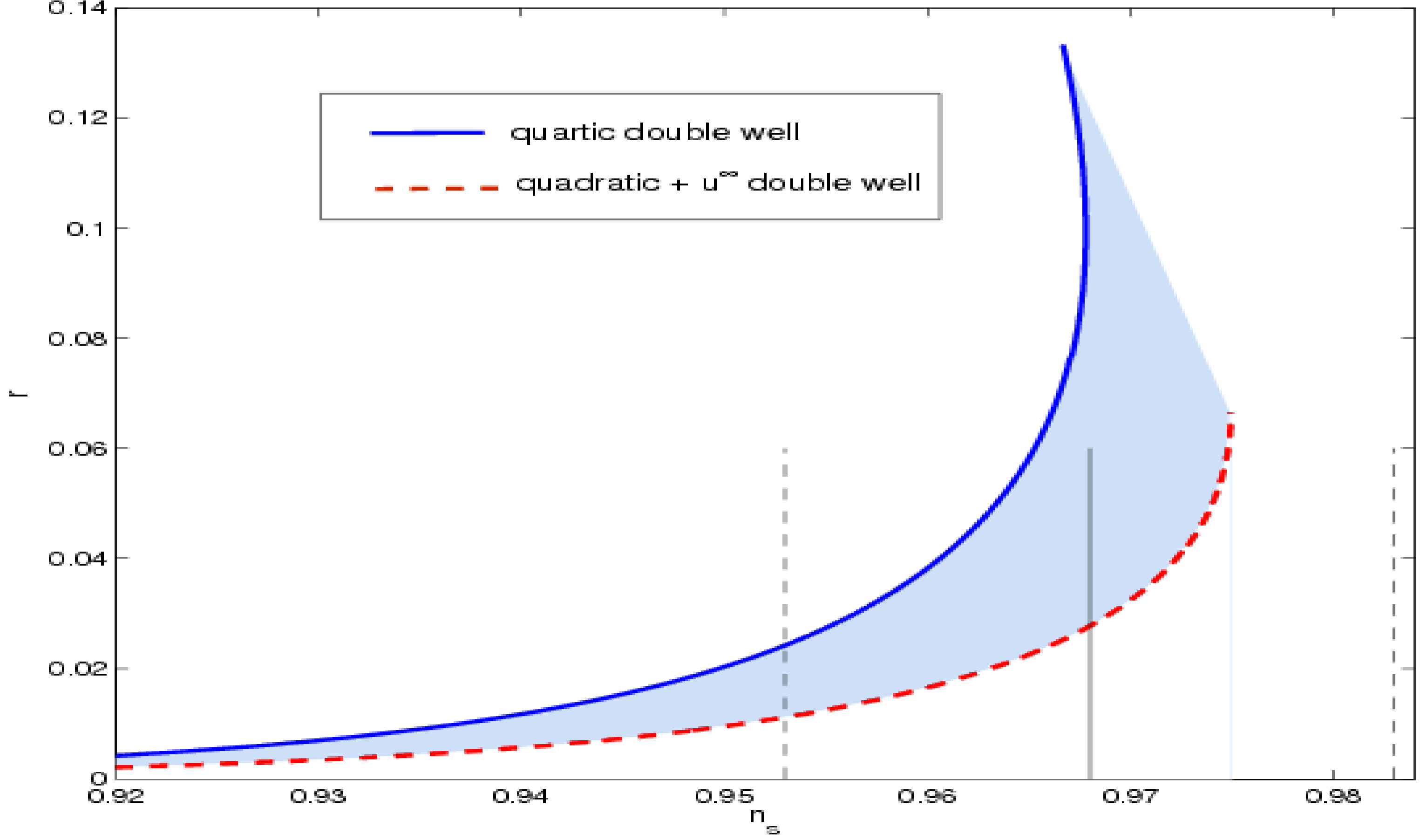
PREDICTIONS

$r < 0.053$

$r > 0.021$

$0.021 < r < 0.053$

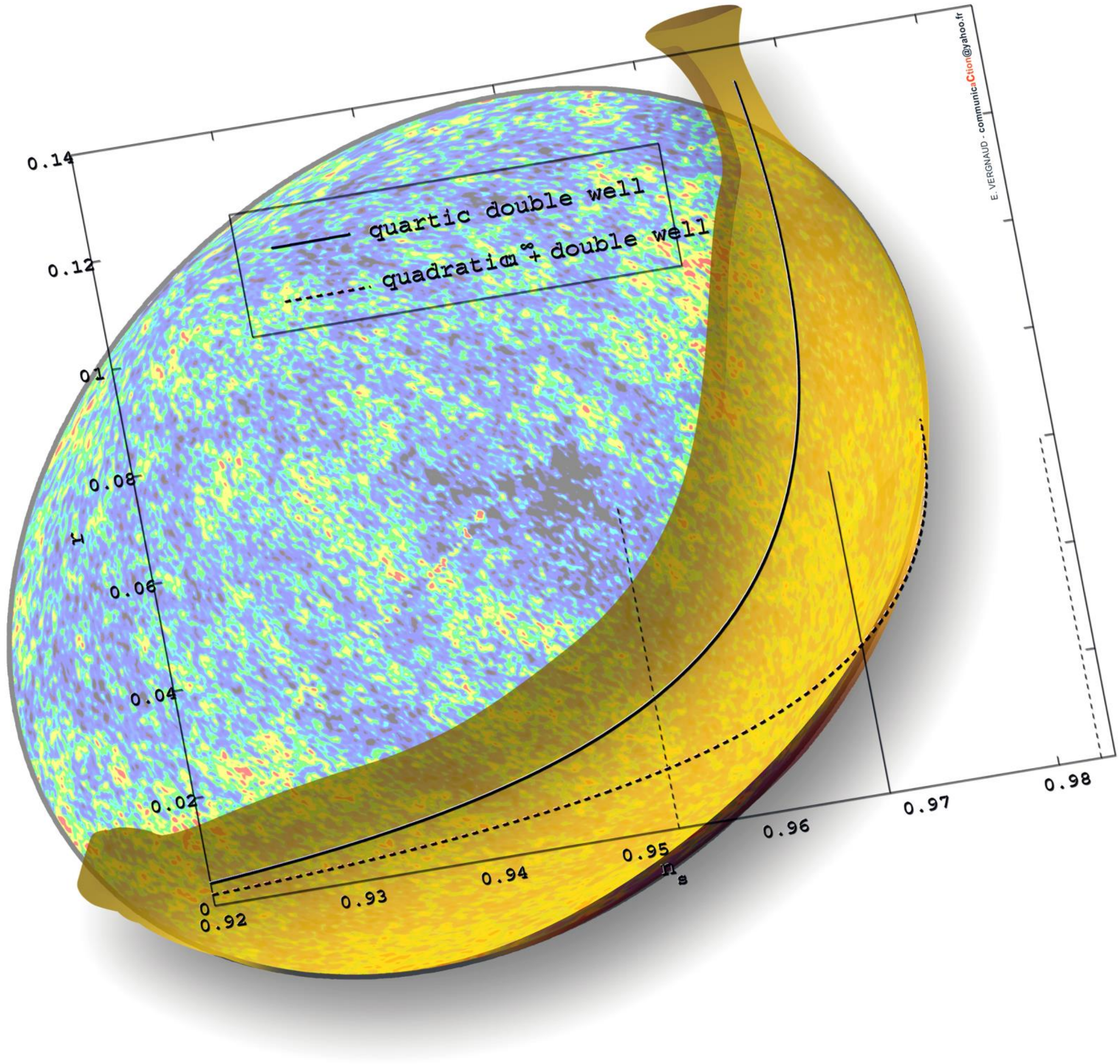
Most probable value: $r \sim 0.051$



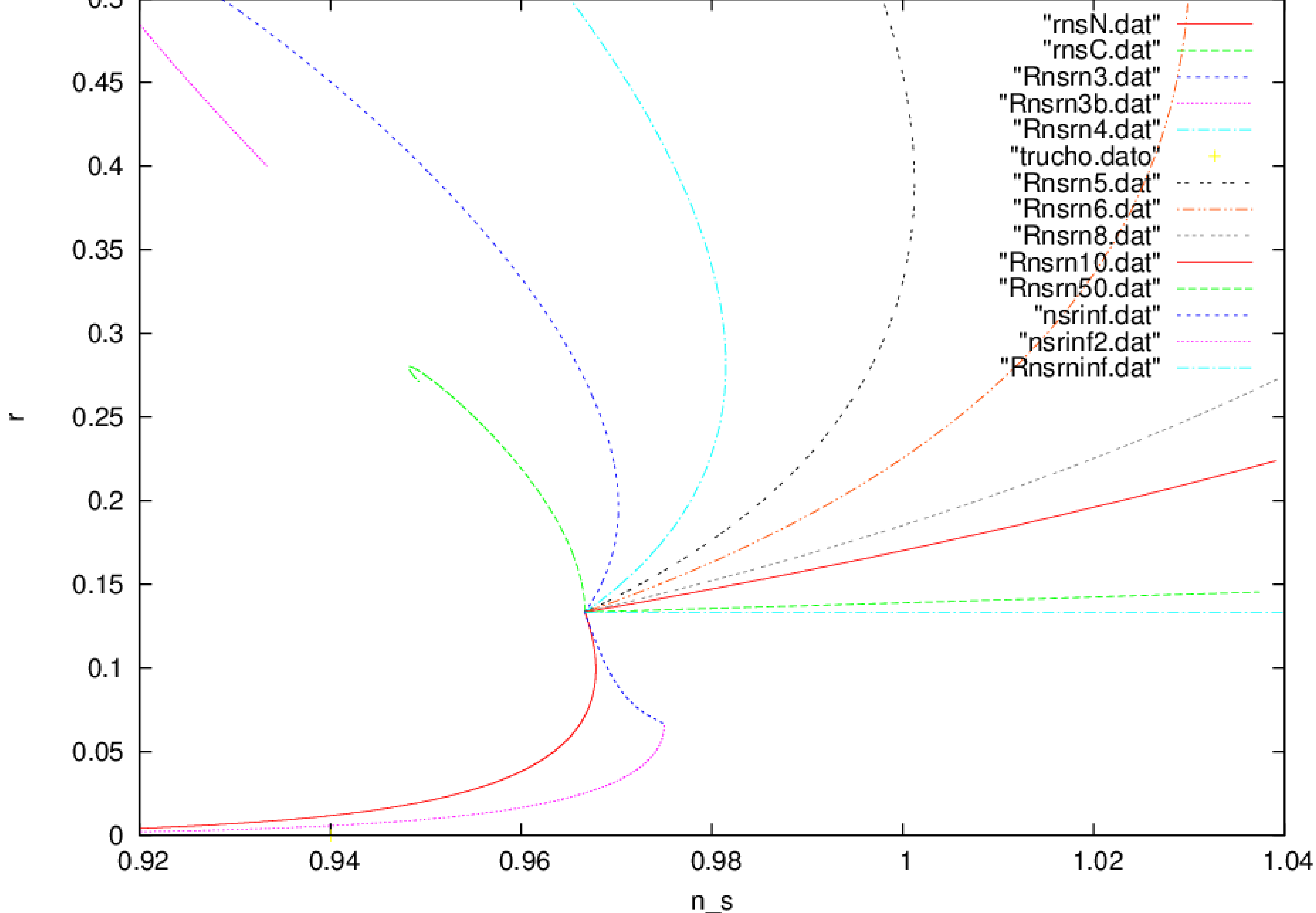
THE PRIMORDIAL COSMIC BANANA

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)



quartic double well
quadratic + double well
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
r
0.92
0.93
0.94
0.95
0.96
0.97
0.98
n_s
E. VERGNAUD - communicaCtion@yahoo.fr



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r
0.45
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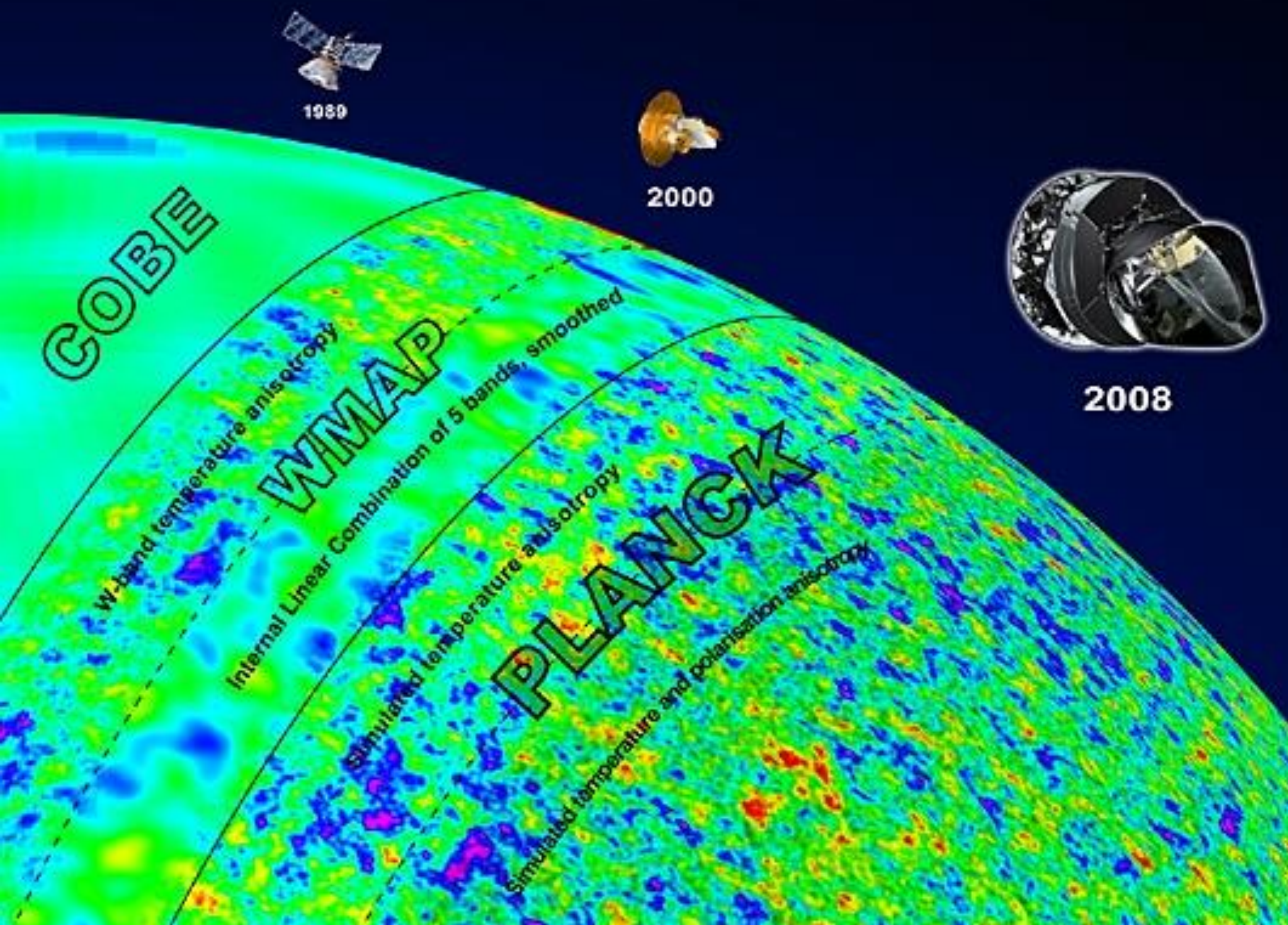
0.05
0
0.92
0.94
0.96
0.98
1
1.02
1.04
n_s

CMB Missions Revolutionise Our Understanding of the Universe



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-**

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??

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)

BLACK HOLE EVAPORATION DOES THE INVERSE EVOLUTION :

BLACK HOLE EVAPORATION GOES FROM CLASSICAL/SEMICLASSICAL STAGE TO A QUANTUM (QUANTUM GRAVITY) STATE,

Through this evolution, the Black Hole temperature goes from the semiclassical gravity temperature (Hawking Temperature) to the usual temperature (the mass) and the quantum gravity temperature (the Planck temperature).

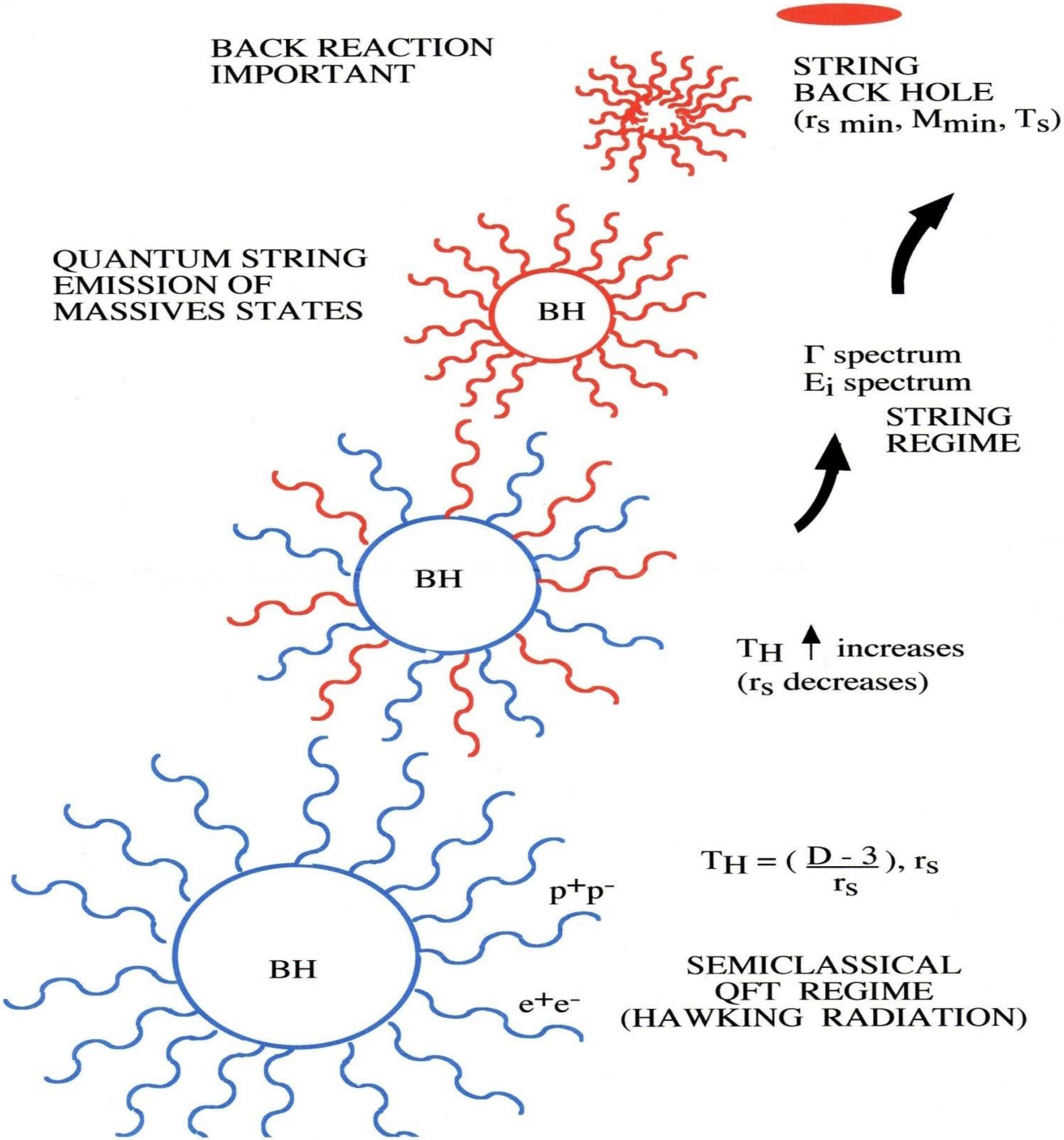
Conceptual unification of quantum black holes, elementary particles and quantum states

CONCEPTUAL UNIFICATION

- **Cosmological evolution goes from a quantum gravity phase to a semi-classical phase (inflation) and then to the classical (present cosmological) phase.**

- **Black Hole Evaporation (BH hole decay rate), heavy particles and extended quantum decay rates; black hole evaporation ends as quantum extended decay into pure (non mixed) non thermal radiation.**

- **The Hawking temperature, elementary particle and Hagedorn (string) temperatures are the same concept in different gravity regimes (classical, semiclassical, quantum) and turn out to be the precise classical-quantum duals of each other.**



BACK REACTION IMPORTANT
STRING BACK HOLE
(r_s min, M_{min}, T_s)
QUANTUM STRING EMISSION OF MASSIVES STATES
BH
Γ spectrum
E_i spectrum
STRING REGIME
BH
T_H ↑ increases
(r_s decreases)
$T_H = (\frac{D-3}{r_s}), r_s$
p^+p^-
BH
e^+e^-
SEMICLASSICAL QFT REGIME (HAWKING RADIATION)

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 are neutral and so weakly interacting that no effects are so far detectable.

Theoretical analysis combined with astrophysical data from galaxy observations as:

- Observed galaxy densities and velocity dispersions.
- Observed galaxy density profiles are cored.
- Acceleration of gravity in the surface of DM dominated galaxies is universal
  $g \simeq 1.7 \times 10^{-11}\, m/s^2 \; = 540 \text{ kpc}/(\text{Gyr})^2$.

points towards a DM particle mass in the keV scale called warm dark matter (WDM). 2 keV = 1/250 electron mass.

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…..

Structure Formation in the Universe

Structures in the Universe as galaxies and cluster of galaxies form out of the small primordial quantum fluctuations originated by inflation just after the big-bang.

These linear small primordial fluctuations grow due to gravitational unstabilities (Jeans) and then classicalize.

Structures form through non-linear gravitational evolution.

Hierarchical formation starts from small scales first.

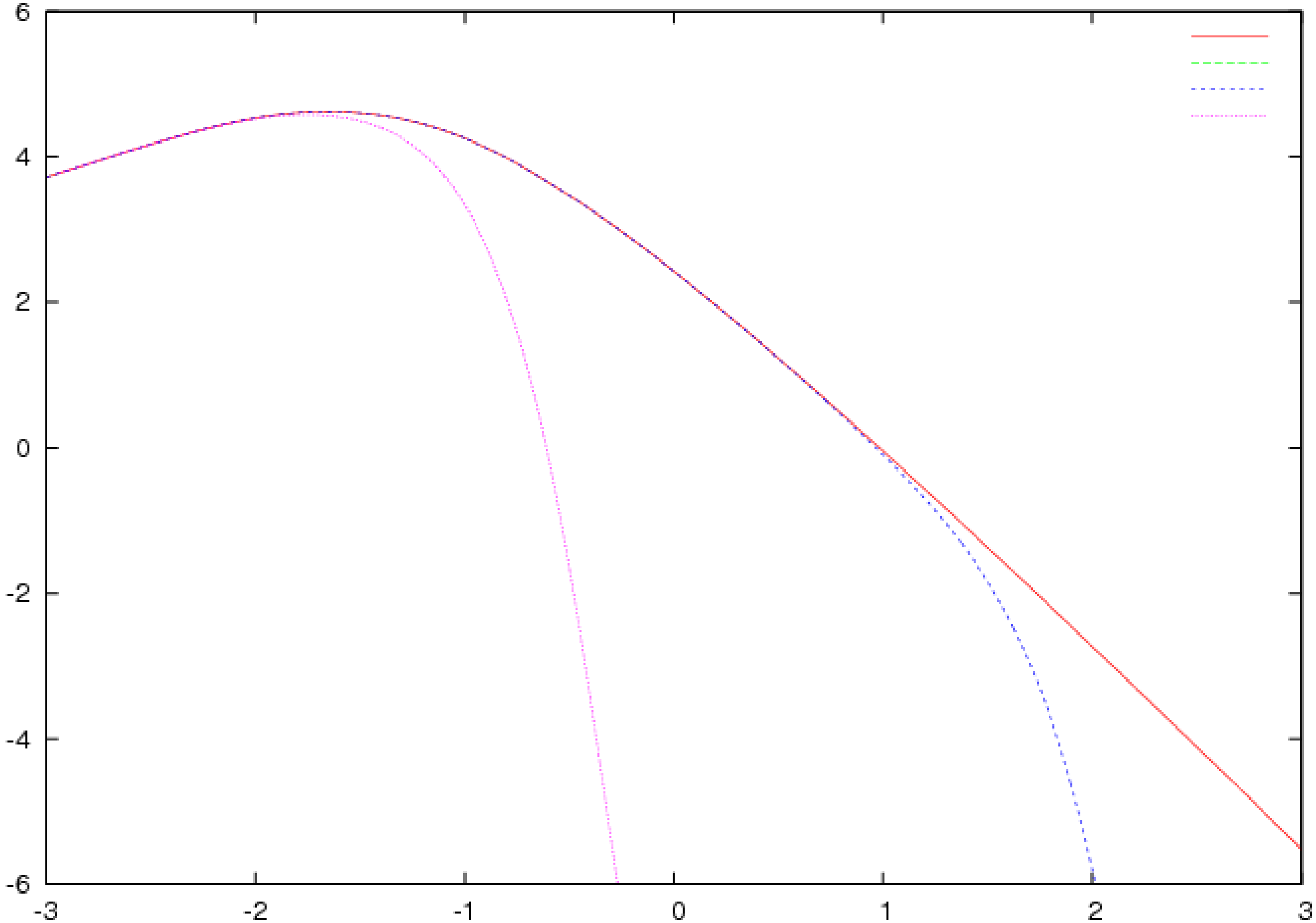
N-body CDM simulations fail to produce the observed structures for small scales less than some kpc.

Both N-body WDM and CDM simulations yield identical and correct structures for scales larger than some kpc.

WDM predicts correct structures for small scales (below kpc) when its quantum nature is taken into account.

Primordial power $P(k)$: first ingredient in galaxy formation.

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

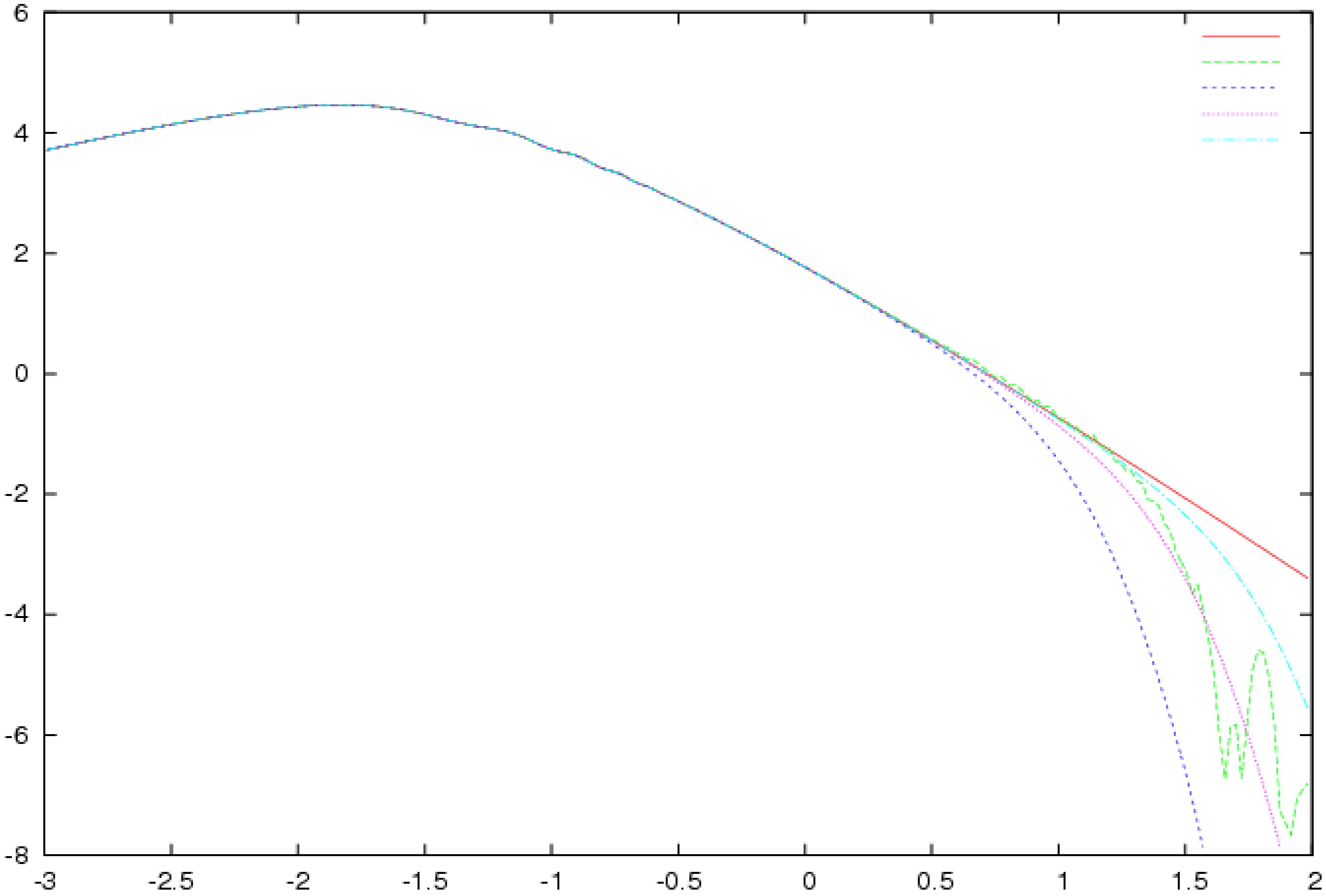


$\log_{10} P(k)$ vs. $\log_{10}[k \text{ Mpc } h]$ for WIMPS, 1 keV DM particles and 10 eV DM particles. $P(k) = P_0 \, k^{n_s} \, T^2(k)$.

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

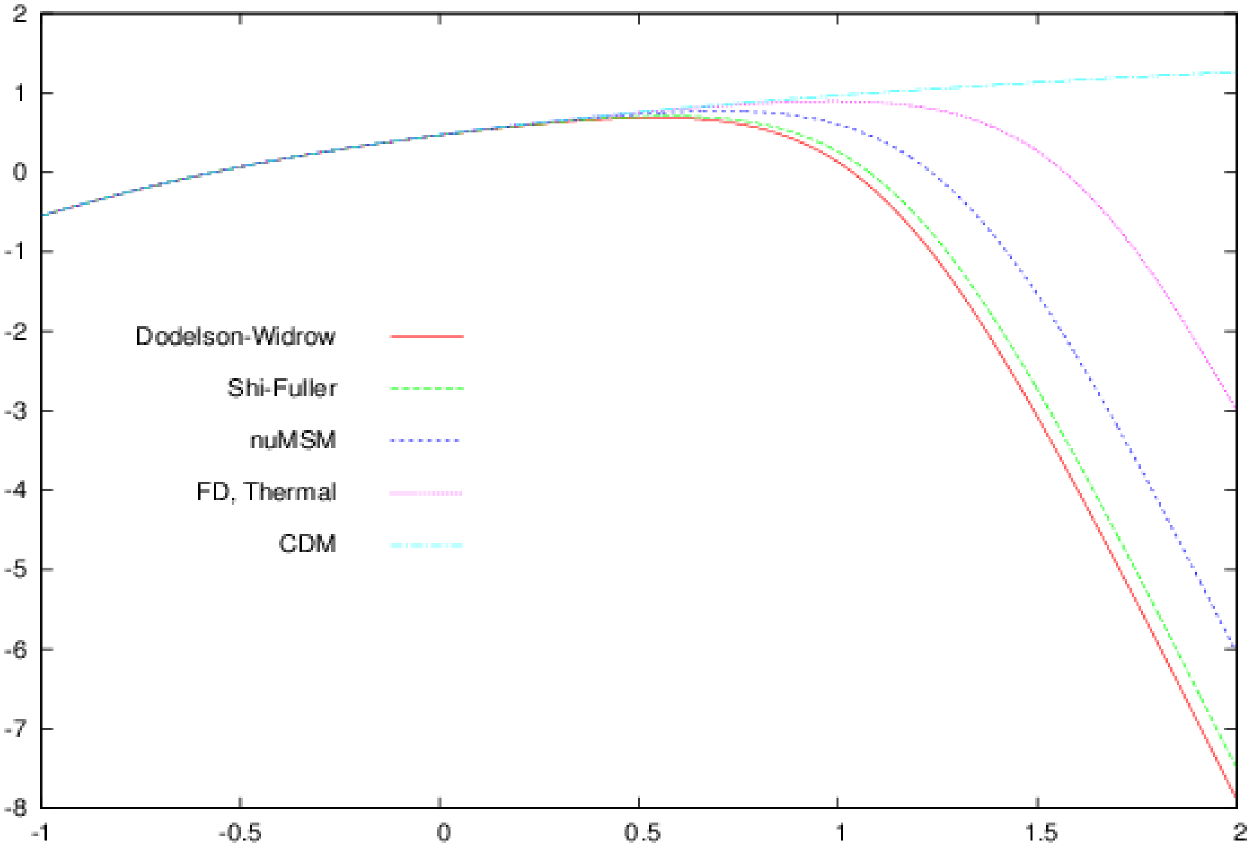
Transfer function in the MD era from Gilbert integral eq

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



$\log_{10} P(k)$ vs. $\log_{10}[k \text{ Mpc } h]$ for CDM, 1 keV, 2 keV, light-blue 4 keV DM particles decoupling in equil, and 1 keV sterile neutrinos. WDM cuts $P(k)$ on small scales $r \lesssim 100\ (\text{keV}/m)^{4/3}$ kpc. CDM and WDM identical for CMB.

Linear primordial power spectrum $\Delta^2(k)$ vs. k Mpc $/h$



$\log_{10} \Delta^2(k)$ vs. $\log_{10}[k \text{ Mpc}/h]$ for a physical mass of 2.5 keV in four different WDM models and in CDM. WDM cuts $\Delta^2(k)$ on small scales. $r \lesssim 73 \, (\text{keV}/m)^{1.45}$ kpc/h.

CDM and WDM are identical for CMB.

Galaxies

Physical variables in galaxies:

a) Nonuniversal quantities: mass, size, luminosity, fraction of DM, DM core radius r_0, central DM density ρ_0, ...

b) Universal quantities: surface density $\mu_0 \equiv r_0\,\rho_0$ and DM density profiles. M_{BH}/M_{halo} (or the halo binding energy).

The galaxy variables are related by universal empirical relations. Only one variable remains free.

Universal quantities may be attractors in the dynamical evolution.

Universal DM density profile in Galaxies:

$$\rho(r) = \rho_0\,F\left(\frac{r}{r_0}\right)\;,\;F(0)=1\;,\;x\equiv\frac{r}{r_0}\;,\;r_0 = \text{DM core radius.}$$

Empirical cored profiles: $F_{Burkert}(x) = \frac{1}{(1+x)(1+x^2)}$.

Cored profiles do reproduce the astronomical observations.

Basement- ground zero of Galaxy Formation

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

de Vega Sanchez – Theory Approach to Galaxy Structure

FERMIONIC QUANTUM WDM and GRAVITATION DETERMINE THE OBSERVED PHYSICAL GALAXY STRUCTURE

-> Dark matter (DM): main component of galaxies. Quantum mechanics: cornerstone of physics from microscopic to macroscopic systems: quantum liquids He3, white dwarf stars, neutron stars. NOT Exotic Physics.

-> Quantum mechanics also responsible of galaxy structures at the kpc scales and below: near the galaxy center, below 10 - 100 pc, the DM quantum effects 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 2014, dVS IJMPA 2016

->Approach to galaxy structure with results in remarkable agreement with observations:

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

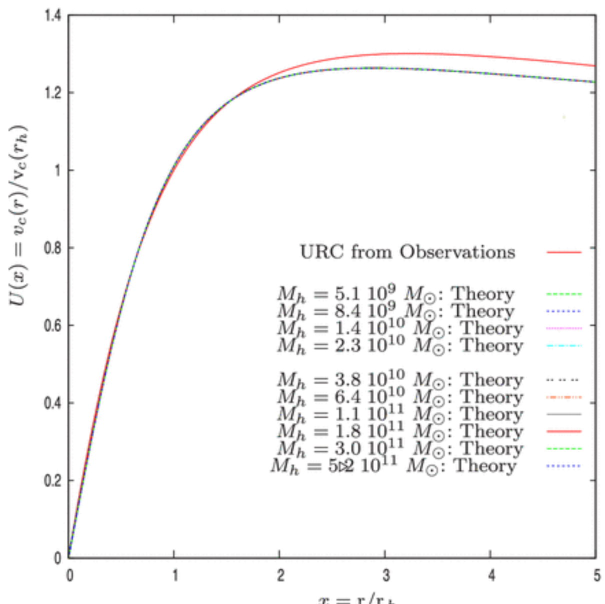
This new framework **requires dark matter particles to be fermionic** with mass in the scale of thousands electron Volts (**keV "warm dark matter")** and described by their quantum mechanical properties, as their quantum pressure resulting from the combination of the Pauli exclusion principle and the 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.

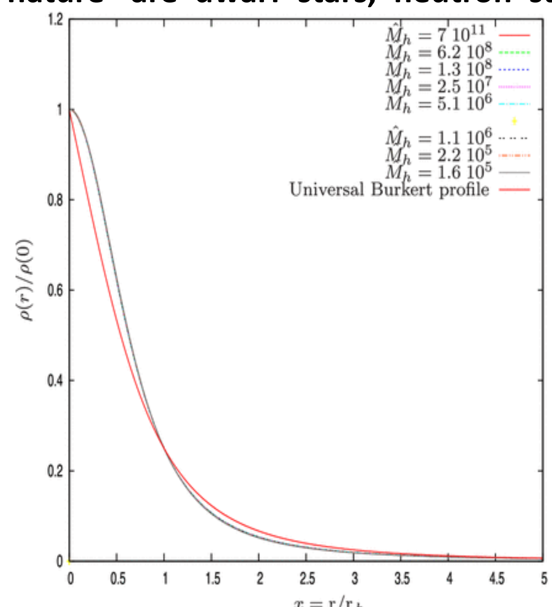
This approach corresponds to the Schrödinger equation in the large number of particles regime **and is for galaxies the analogue of the Thomas-Fermi approach for atoms, with gravitation instead of the electric potential**.

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

<u>Rotation curves (left panel):</u> The theoretical curves for 10 different galaxy masses all fall one into each other <u>providing an Universal Rotation Curve (URC)</u> which remarkably coincides with the observed universal curve (displayed in red) . Small deviations show up only at distances outside twice *the halo 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 quantum macroscopic objects in nature are dwarf stars, neutron stars and the liquid Helium 3).





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.

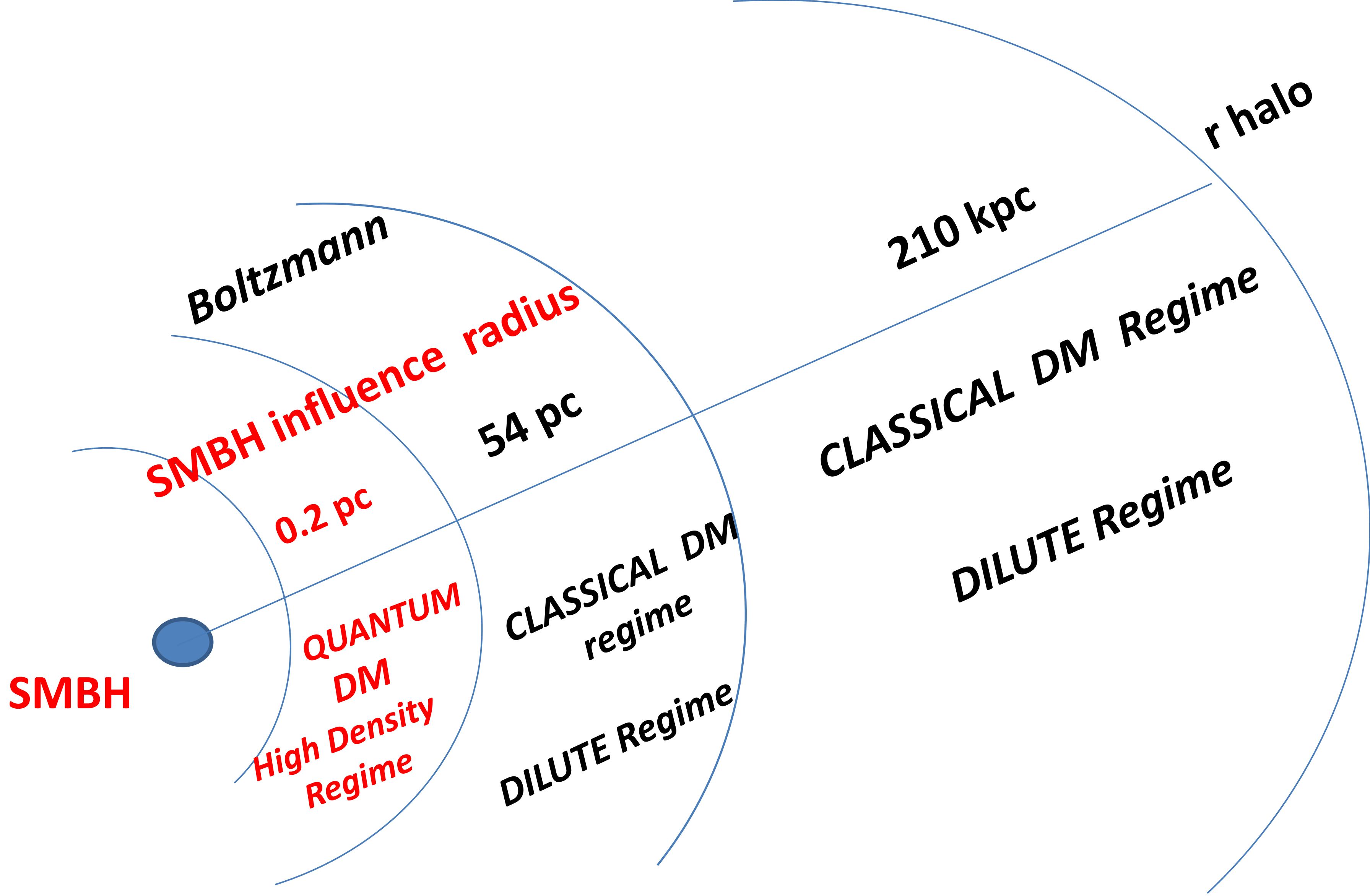
Interestingly enough, small deviations from the exact scaling relations show up for compact dwarf galaxies as a manifestation of the quantum macroscopic effects present in these galaxies.

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)



WDM Thomas-Fermi Galaxy Theory with SMBH

de Vega & Sanchez, 2017

UPDATE and CLARIFICATIONS

ΛCDM agrees with CMB + LSS BUT
ΛCDM DOES NOT agree with SSS (GALAXIES)

ΛWDM agrees with CMB + LSS + SSS (GALAXIES)
The Standard Model of the Universe is LWDM =
{GR, Newtonian Gravity, Field Theory, QFT}

Sentences like « CMB confirms the ΛCDM model … »
Must be completed by adding: « in the large scales" »
and must be updated with the sentence:
CMB confirms the ΛWDM model in large scales

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

DARK MATTER UPDATE

- **THERE IS NO CUSP/CORE problem:**
  - **Observed Galaxy profiles are cored.**
  - **WDM Galaxy density profiles are cored**

- **THERE IS NO satellite problem**
  - **WDM abundance of structures agrees with observations**

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

NO DM WIMPS, NO DM annhilation,

NO DM axions. NO DM bosons

ΛWDM Cosmology

(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. Generalized Eddington approach to galaxies

(i) Dwarf galaxies are 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-

- **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.

- **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.**
- **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.

Minimal galaxy mass from degenerate WDM

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

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

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

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

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

Summary Warm Dark Matter, WDM: $m \sim$ keV

- Large Scales, structures beyond ~ 100 kpc: WDM and CDM yield identical results which agree with observations
- Intermediate Scales: WDM give the correct abundance of substructures.
- Inside galaxy cores, below ~ 100 pc: N-body classical physics simulations are incorrect for WDM because of important quantum effects.
- Quantum calculations (Thomas-Fermi) give galaxy cores, galaxy masses, velocity dispersions and densities in agreement with the observations.
- Direct Detection of the main WDM candidate: the sterile neutrino. Beta decay and electron capture. ^{3}H, Re, Ho.

So far, not a single valid objection arose against WDM.
Baryons (=16%DM) expected to give a correction to WDM

• 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.**

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 galaxies 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 results, consistent with the fact that dark matter is in average six times more abundant than baryons.

Axions are ruled out as dark matter

Hot Dark Matter (eV particles or lighter) are ruled out because their free streaming length is too large $\gtrsim$ Mpc and hence galaxies are not formed.

A Bose-Einstein condensate of light scalar particles evades this argument because of the quantum nature of the BE condensate. $r_{Jeans} \sim 5$ kpc implies $m_{axion} \sim 10^{-22}$ eV.

The phase-space density $Q = \rho/\sigma^3$ decreases during structure formation: $Q_{today} < Q_{primordial} \propto m^4$.
Computing $Q_{primordial}$ for a DM BE condensate we derived lower bounds on the DM particle mass m using the data for Q_{today} in dwarf galaxies:

TE: $m \geq 0.155 \text{ MeV} \left(\frac{25}{g_d}\right)^{5/3}$. Out of TE: $m \geq 14 \text{ eV} \left(\frac{25}{g_d}\right)^{5/3}$

Axions with $m \sim 10^{-22}$ eV are ruled out as DM candidates.

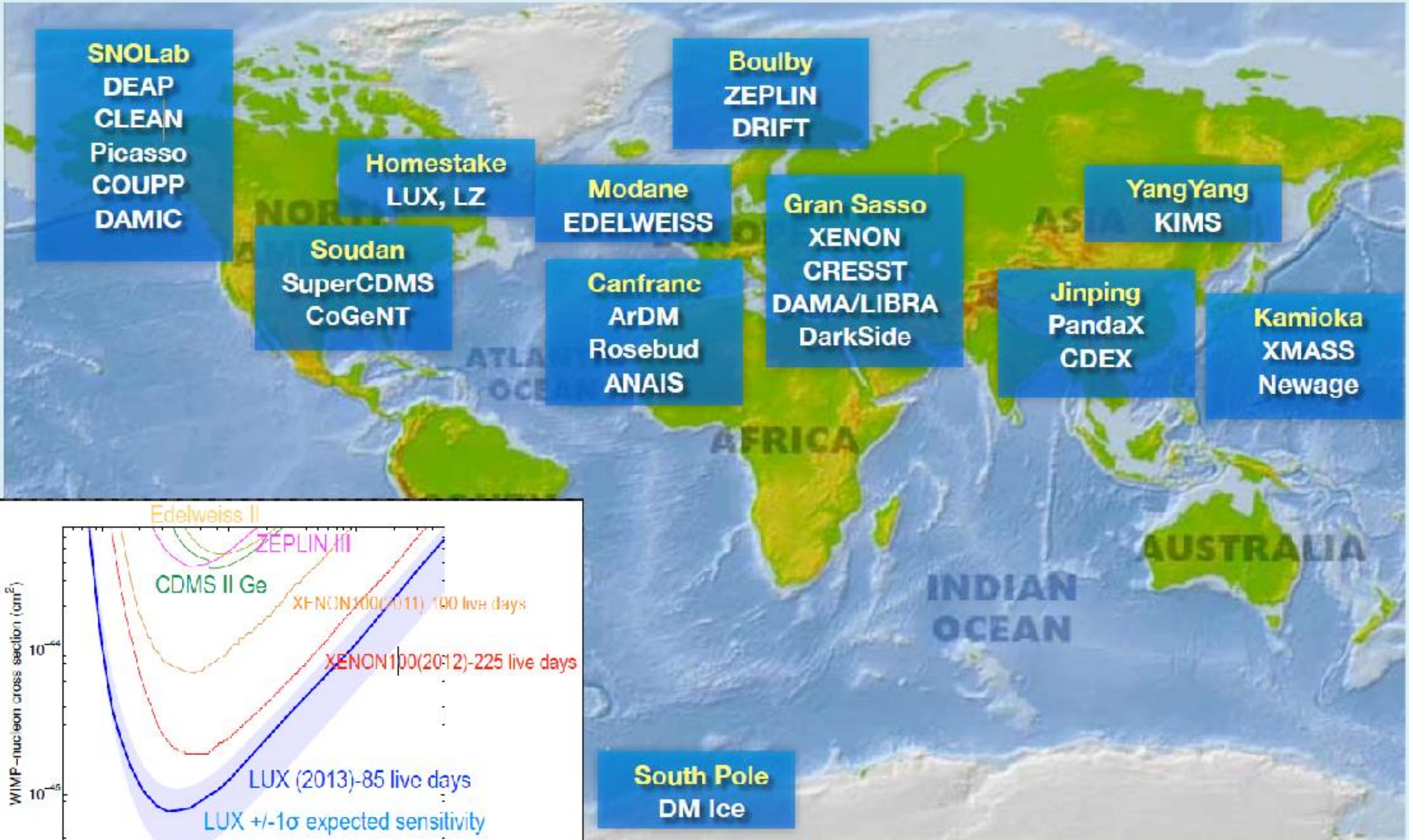
D. Boyanovsky, H. J. de Vega, N. G. Sanchez, PRD 77, 043518 (08). H. de Vega, N. Sanchez, arXiv:1401.1214

- **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**

Dans le monde entier



DARK MATTER UPDATE

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- **WDM Galaxy density profiles are cored**

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- In addition, these are not fundamental problems.

NO DM WIMPS, NO DM annhilation,

NO DM axions

Summary and Conclusions

- Combining theoretical evolution of fluctuations through the Boltzmann-Vlasov equation with galaxy data points to a DM particle mass 3 - 10 keV. T_d turns to be model dependent. The keV mass scale holds independently of the DM particle physics model.
- Universal Surface density in DM galaxies [$\mu_{0D} \simeq (18 \text{ MeV})^3$] explained by keV mass scale DM. Density profile scales and decreases for intermediate scales with the spectral index n_s : $\rho(r) \sim r^{-1-n_s/2}$ and $\rho(r) \sim r^{-2}$ for $r \gg r_0$.

H. J. de Vega, P. Salucci, N. G. Sanchez, 'The mass of the dark matter particle from theory and observations', New Astronomy, 17, 653 (2012).

H. J. de Vega, N. Sanchez, 'Model independent analysis of dark matter points to a particle mass at the keV scale', MNRAS 404, 885 (2010).

HIGHLIGHTS

(0)The Standard Model of the Universe Includes Inflation

(I) LATEST PREDICTIONS :

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

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

Clarification and Simplification

GALAXY FORMATION IN AGREEMENT WITH OBSERVATIONS

Analytical Results and Numerical (including analytical) Results

Future Perspectives: Detection!

Sterile neutrino detection depends upon the particle physics model. There are sterile neutrino models where the keV sterile is stable and thus hard to detect.

Astronomical observation of steriles:
X-ray data from galaxy halos.

Direct detection of steriles in Lab:

Bounds on mixing angles from
Mare, Katrin, ECHo, Project 8 and PTOLEMY are expected.

For a particle detection a dedicated beta decay or electron capture experiment looks necessary to search sterile neutrinos with mass around 2 keV.

Calorimetric techniques seem well suited.

Best nuclei for study:

Electron capture in ^{163}Ho, beta decay in ^{187}Re and Tritium.

X-ray detection of DM sterile neutrinos

Sterile neutrinos ν_s decay into active neutrinos ν_e plus X-rays with a lifetime $\sim 10^{11} \times$ age of the universe.

These X-rays may be seen in the sky looking to galaxies ! recent review: C. R. Watson et al. JCAP, (2012).

Future observations:

- Satellite projects: Xenia (NASA), ASTRO-H (Japan).
- CMB: WDM decay distorts the blackbody CMB spectrum. The projected PIXIE satellite mission (A. Kogut et al.) can measure WDM sterile neutrino mass.
- PTOLEMY experiment: Princeton Tritium Observatory. Aims to detect the cosmic neutrino background and WDM (keV scale) sterile neutrinos through the electron spectrum of the Tritium beta decay induced by the capture of a cosmic neutrino or a WDM sterile neutrino.
- HOLMES electron capture in ^{163}Ho calorimeter G Sasso

Usually, (littérature, conferences…), CDM is « granted » as « the » DM . And wimps as « the » DM particle.
In most work on CDM galaxies and galaxy formation simulations, the problems to agree with observations lead to cyclic CDM crisis, with more epicyclic type of arguments and recipes. Each time CDM is in trouble, recipes to make it alive for a while are given and so on. CDM galaxy formation turns around this situation from more than 20 years. The subject is turning around around itself.
(Moreover, such crisis led to wrongly replace DM by replacing laws of physics….) .
While on the past 20 years, cosmology, early and late universe, inflation, CMB , LSS, SSS, made progress and clarifications, Galaxy formation becames an increasingly « Ptolomeic » subject , a list of recipes or ad hoc prescriptions, « termed «astrophysical solutions » or « baryonic solutions » to CDM which exited from a scientific physical framework…. Namely, in CDM dominated galaxies, baryons,complexes environments and feedbacks need to make all the work…!!). CDM is the wrong solution to Galaxies and its Formation.

Dark Energy

$76 \pm 5\%$ of the present energy of the Universe is Dark !
Current observed value:
$\rho_\Lambda = \Omega_\Lambda \, \rho_c = (2.39 \text{ meV})^4$, $1 \text{ meV} = 10^{-3}$ eV.
Equation of state $p_\Lambda = -\rho_\Lambda$ within observational errors.
Quantum zero point energy. Renormalized value is finite.
Bosons (fermions) give positive (negative) contributions.
Mass of the lightest particles ~ 1 meV is in the right scale.
Spontaneous symmetry breaking of continuous symmetries produces massless scalars as Goldstone bosons. A small symmetry breaking provide light scalars: axions,majorons...
Observational Axion window $10^{-3} \text{ meV} \lesssim M_{\text{axion}} \lesssim 10 \text{ meV}$.
Dark energy can be a cosmological zero point effect. (As the Casimir effect in Minkowski with non-trivial boundaries).
We need to learn the physics of light particles (< 1 MeV), also to understand dark matter !!

My Current work in SU

-Scaling Laws: Mass-Size Relations :
At different Scales

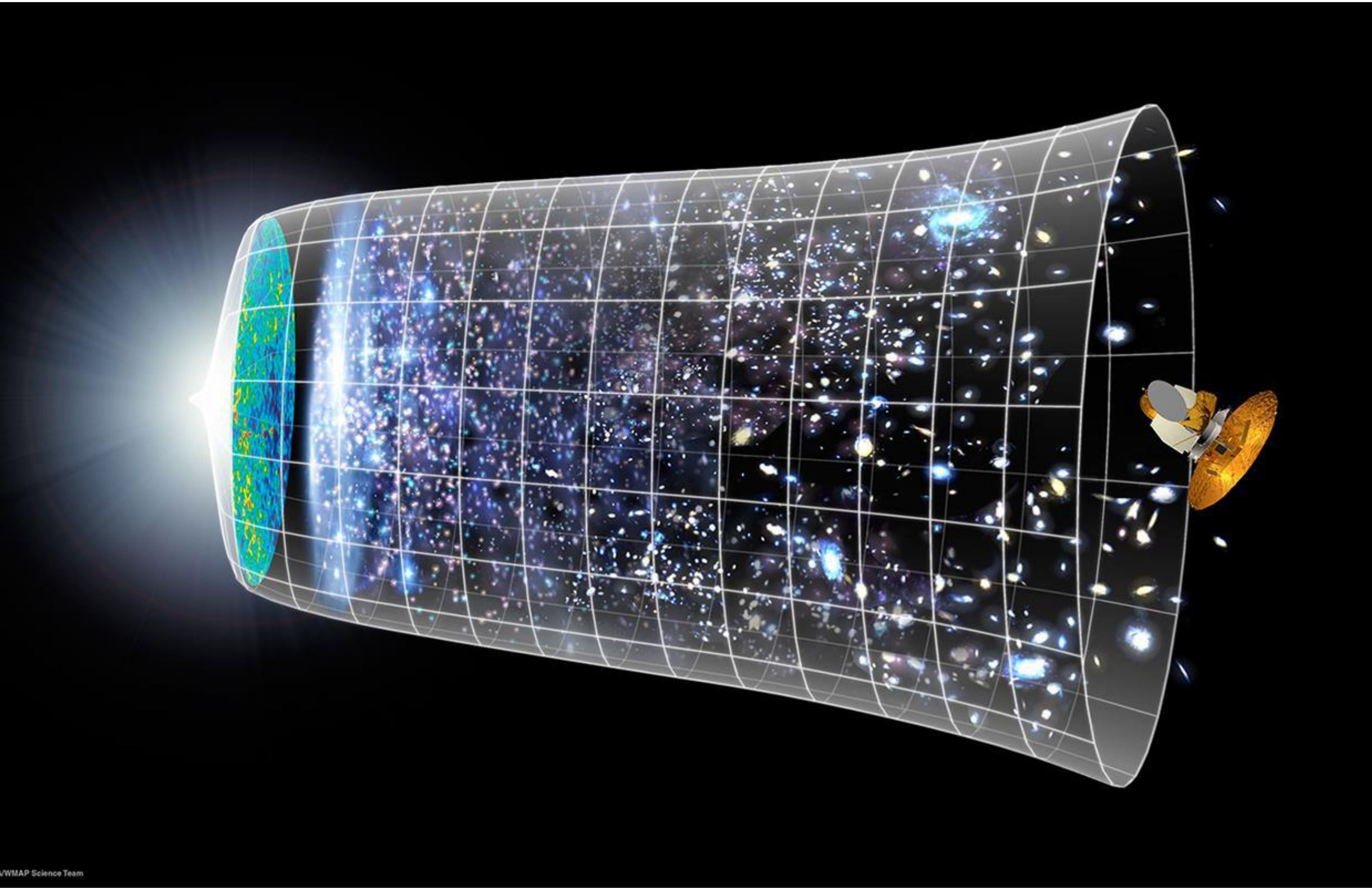
-Surface Densities: At different scales and in Different types of structures

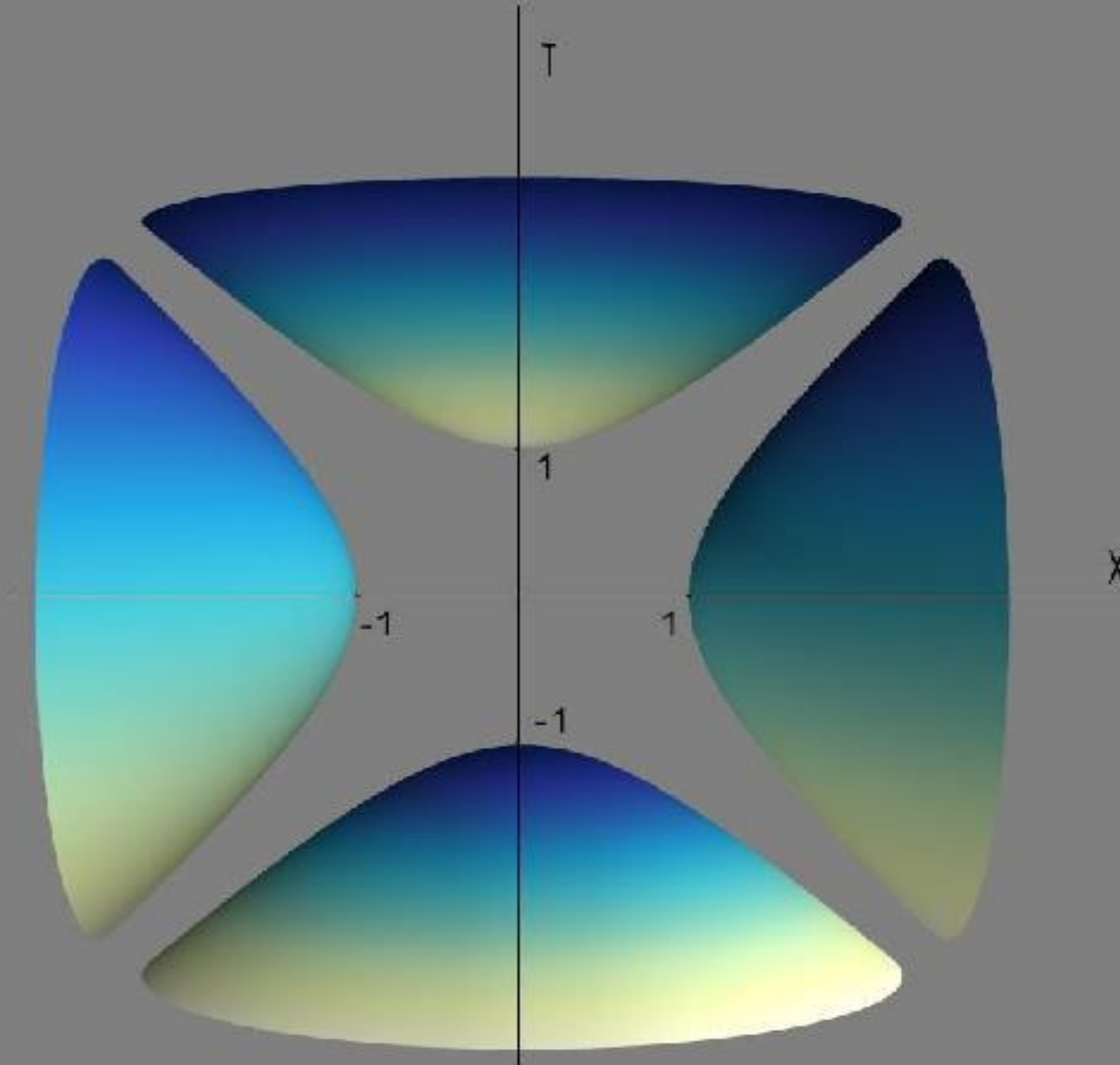
-Universality (or quasi Universality) features

-dVS Thomas-Fermi-Theory for Stellar Structure Black Holes

-Towards a Theory of Structures in the Universe

-Star Formation in WDM


/WMAP Science Team



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1
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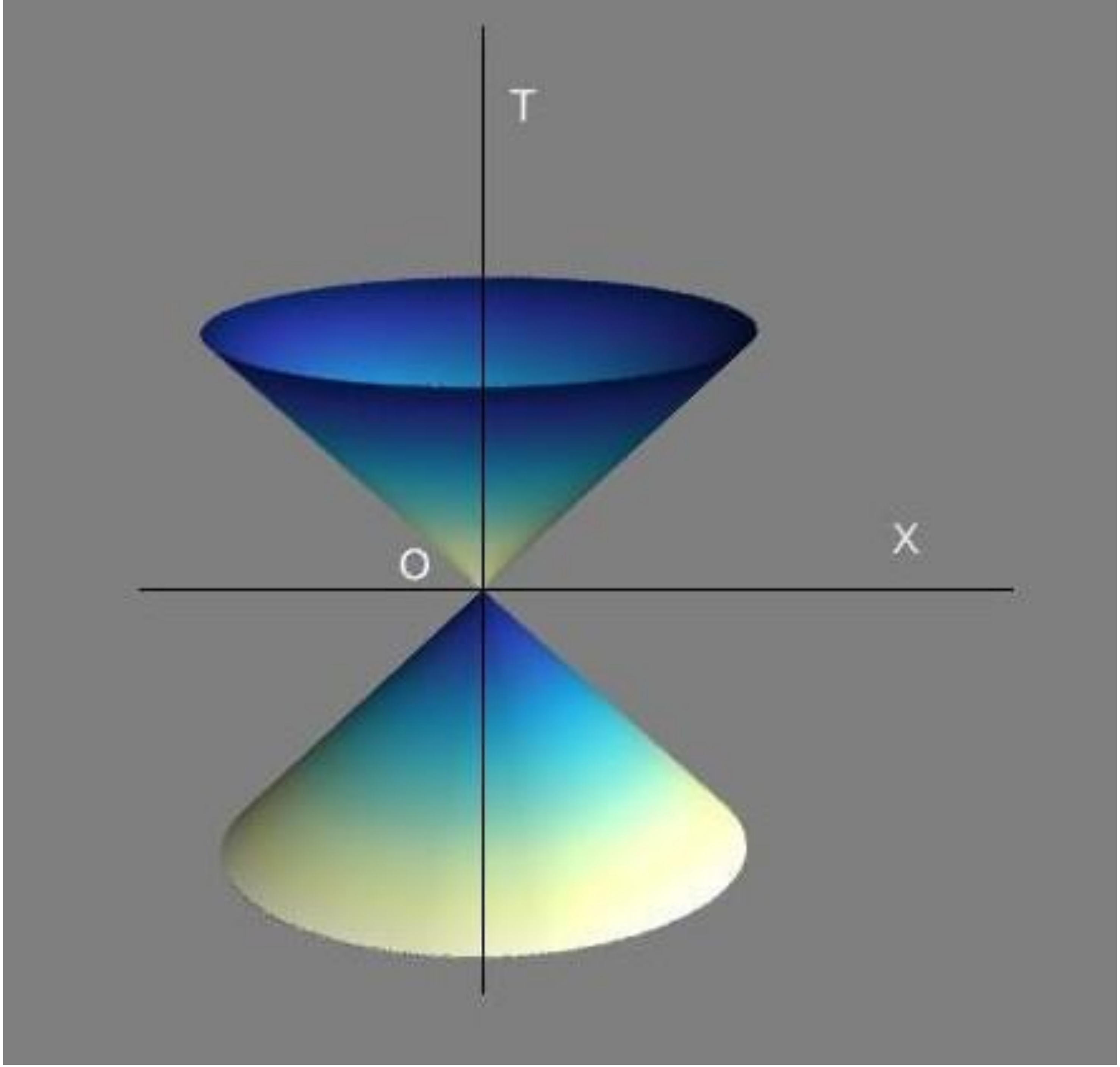
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FIN…

THE END….

MUCHISIMAS GRACIAS

por vuestra ATENCION !!!

MERCI beaucoup pour votre ATTENTION !!

THANK YOU very much for your ATTENTION !!

LE TEMPS: CONCEPTS

- CAUSALITE, VITESSE MAXIMALE: c. PASSE, PRESENT, FUTURE: CONE DE LUMIERE

- IRREVERSIBILITE : LA FLECHE DU TEMPS
- →→→

- L'UNIVERS évolue DU DESORDRE VERS l'ORDRE (DU CHAOS VERS l'STRUCTURATION): => ENTROPY, toujours CROIT

- LA GRAVITATION ESPACE-TEMPS

- CLASSIQUE vs QUANTIQUE

- LE TEMPS est un concept CLASSIQUE
- EMERGE a partir du QUANTIQUE
- ORIGIN DU TEMPS
- VIDE (RIEN) : VIDE QUANTIQUE (pas de temps)=>
- EMERGENCE du TEMPS

A NEW QUANTUM WORLD at the Planck Scale

$$m_p = (hc/G)^{1/2}$$

Norma G. Sanchez

In the Chalonge - de Vega Open Session

29 March 2018

THE NEW QUANTUM STRUCTURE OF THE SPACE-TIME

- **THE CLASSICAL - QUANTUM DUALITY OF NATURE :**

- $O_G = o_P^2 / O_Q$, $L_G = l_P^2 / L_Q$, $L_G = 2GM / c^2$, $L_Q = h / Mc$

- **THE SPACE TIME (X, T) Coordinates as**
- **QUANTUM NON COMMUTING OPERATORS :** $[X, T] = 1$

° THE SPACE-TIME AS a QUANTUM HARMONIC OSCILLATOR :

$[X, P] = i$, $2H = X^2 + P^2 = 2N + 1$, $[2H, X] = -iP$, $[2H, P] = iX$

$P = iT$:

$[X, T] = 1$, $2H = X^2 - T^2 = 2N + 1$, $[2H, X] = T$, $[2H, T] = X$

QUANTUM SPACE-TIME

- $(T^2 - X^2) - 1 \geq 0$: ***timelike***
- $(X^2 - T^2) - 1 \geq 0$: ***spacelike***
- $(T^2 - X^2) - 1 = 0$, ***null : the "quantum light- cone".***

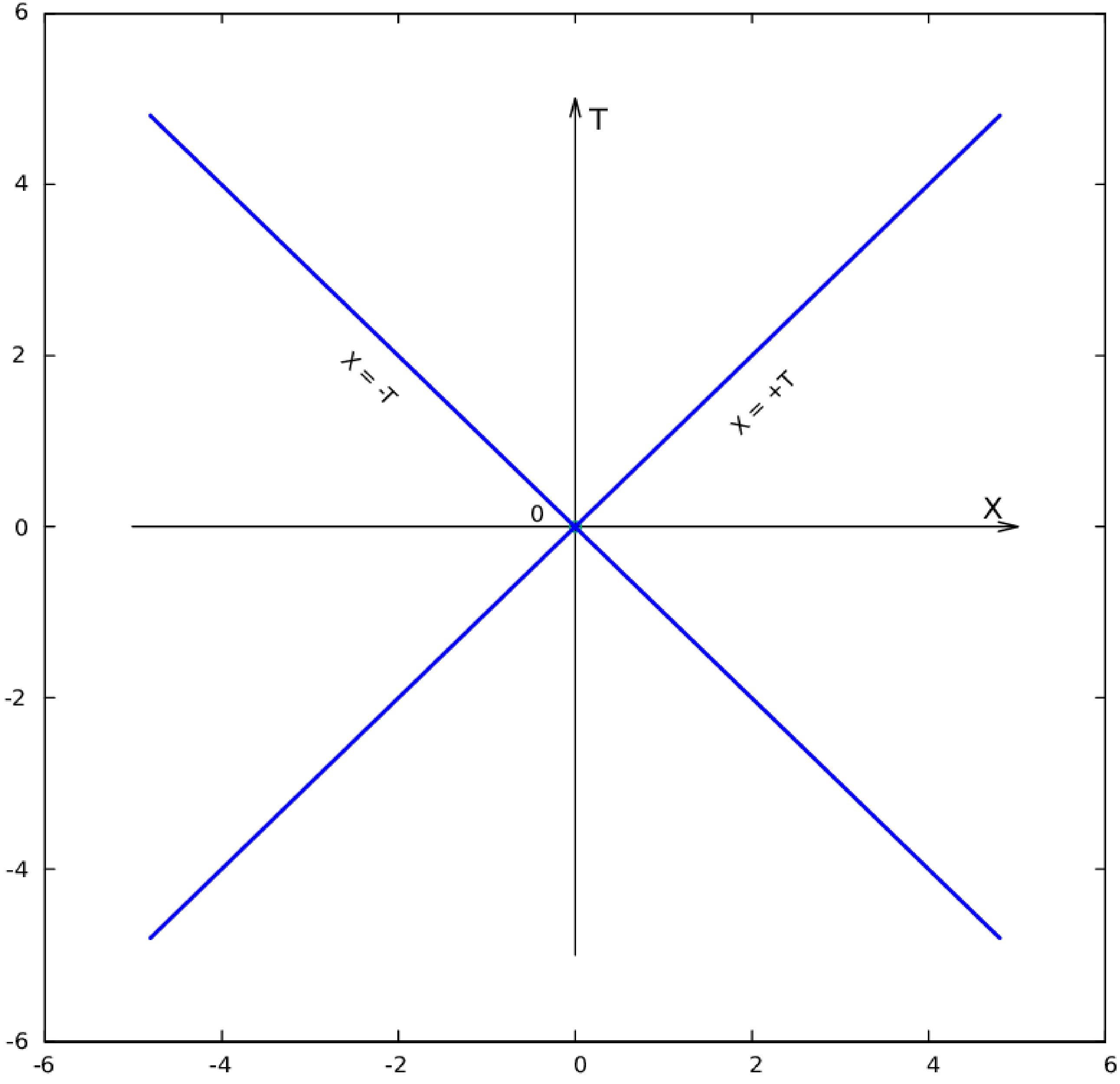
$$(X^2 - T^2)_n = 2n + 1$$ **: discrete levels**

$$(X^2 - T^2) = \pm[X, T] = \pm 1, \quad 1 = 2\varepsilon_0, \quad (n = 0)$$

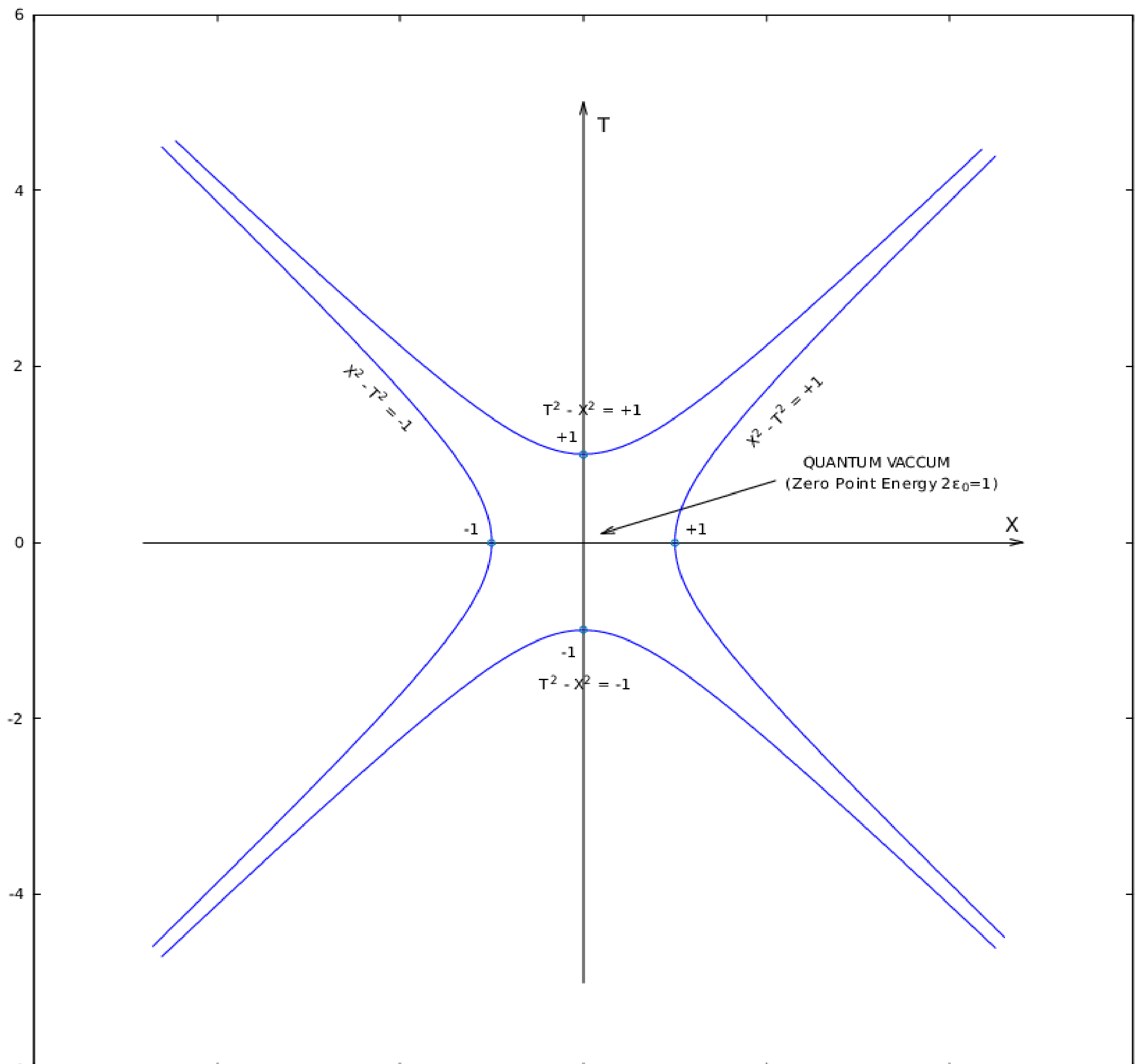
the quantum light cone

- $[X, T] = 0$: $X = \pm T$ **the classical light cone.**

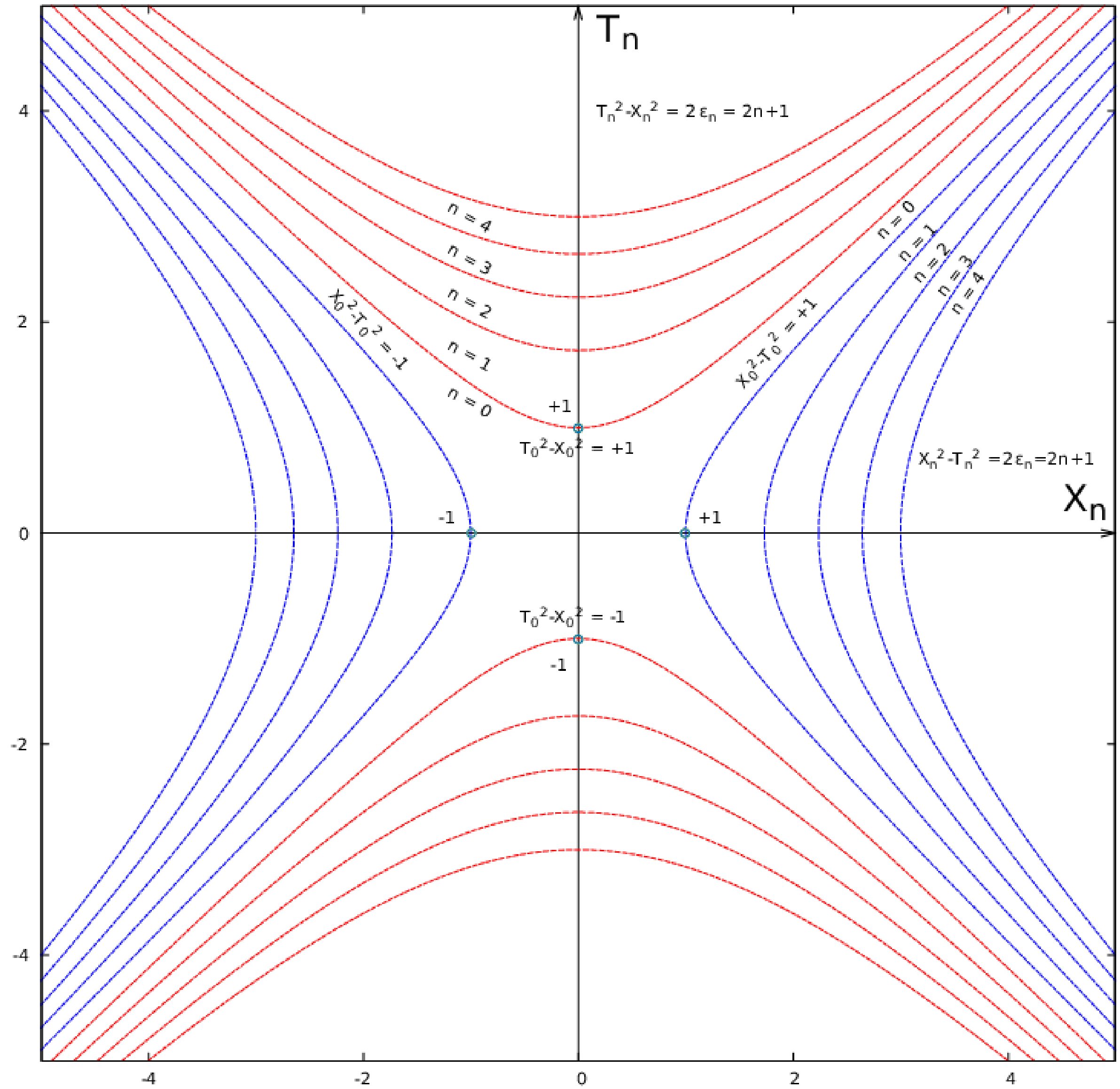
THE CLASSICAL LIGHT CONE



THE QUANTUM LIGHT CONE



QUANTUM SPACE-TIME STRUCTURE



- ***Science is built up with facts,***
- ***as a house is with stones.***
- ***But a collection of facts is no more a science***
- ***than a heap of stones is a house.***

-- Henri Poincaré

- ***La science est construit avec des faits,***
- ***ainsi comme une maison est construite***
- ***avec des pierres.***
- ***Mais une collection de faits n'est pas une science, ainsi comme un tas de pierres n'est pas une maison.***

Richard P. Feynman foresaw the necessity to include quantum physics in simulations in 1981

“I’m not happy with all the analyses that go with just the classical theory, because nature isn’t classical, dammit, and if you want to make a simulation of nature, you’d better make it quantum mechanical, and by golly it’s a wonderful problem, because it doesn’t look so easy.”

Feynman again:

“It doesn’t matter how beautiful your theory is, it doesn’t matter how smart you are. If it doesn’t agree with experiment, it’s wrong.
R. P. Feynman”

THANK YOU VERY MUCH
FOR YOUR ATTENTION!!

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".**

What next for the LHC?

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

PREDICTIONS :

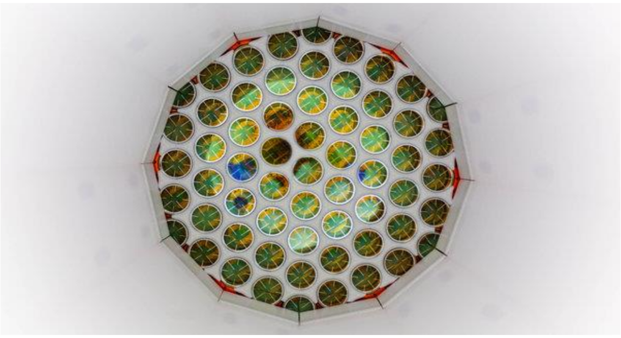
NO Dark Matter at LHC

NO SUSY at LHC

LUX Large Underground Xenon Detector

30 October 2013

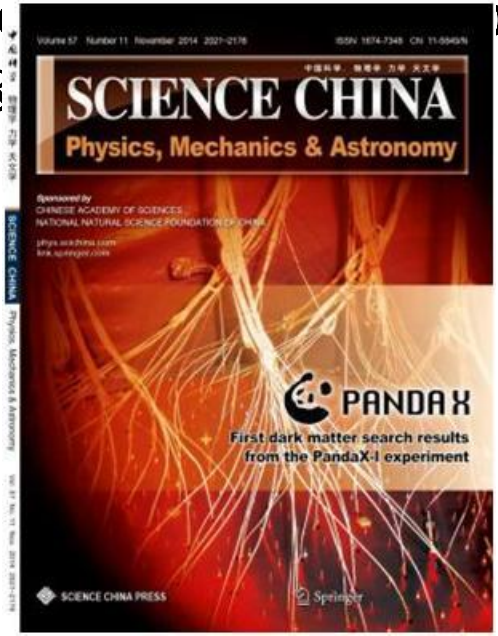
Dark Matter Experiment Has Detected Nothing, Researchers Say Proudly



- **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[illegible]based journal *Science China Physics, Mechanics &*

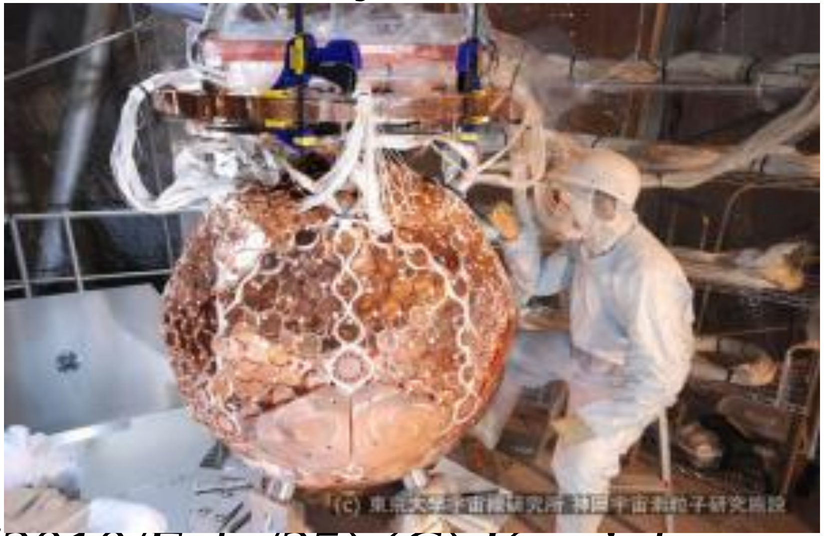


- **NEGATIVE RESULTS**
- **for Wimps**
- **China Science Press**

- **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*

More Ongoing Experiments...

RECENT NEWS

->October 2015: DAMIC for m < 10 GeV.

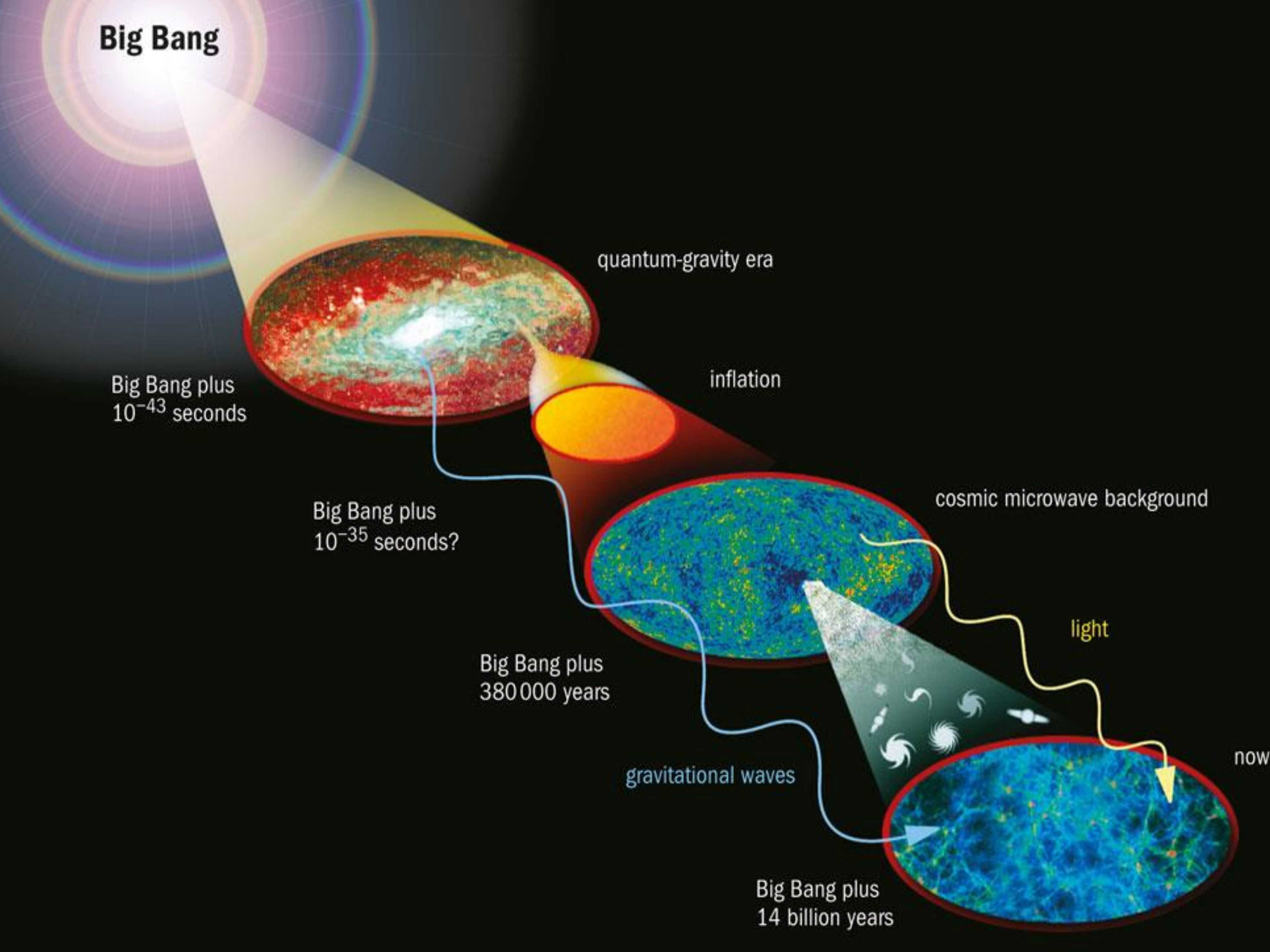
SNOLab Ontario, Canada

->October 2015: DARK-SIDE since October 2013 at Gran Sasso, Italy

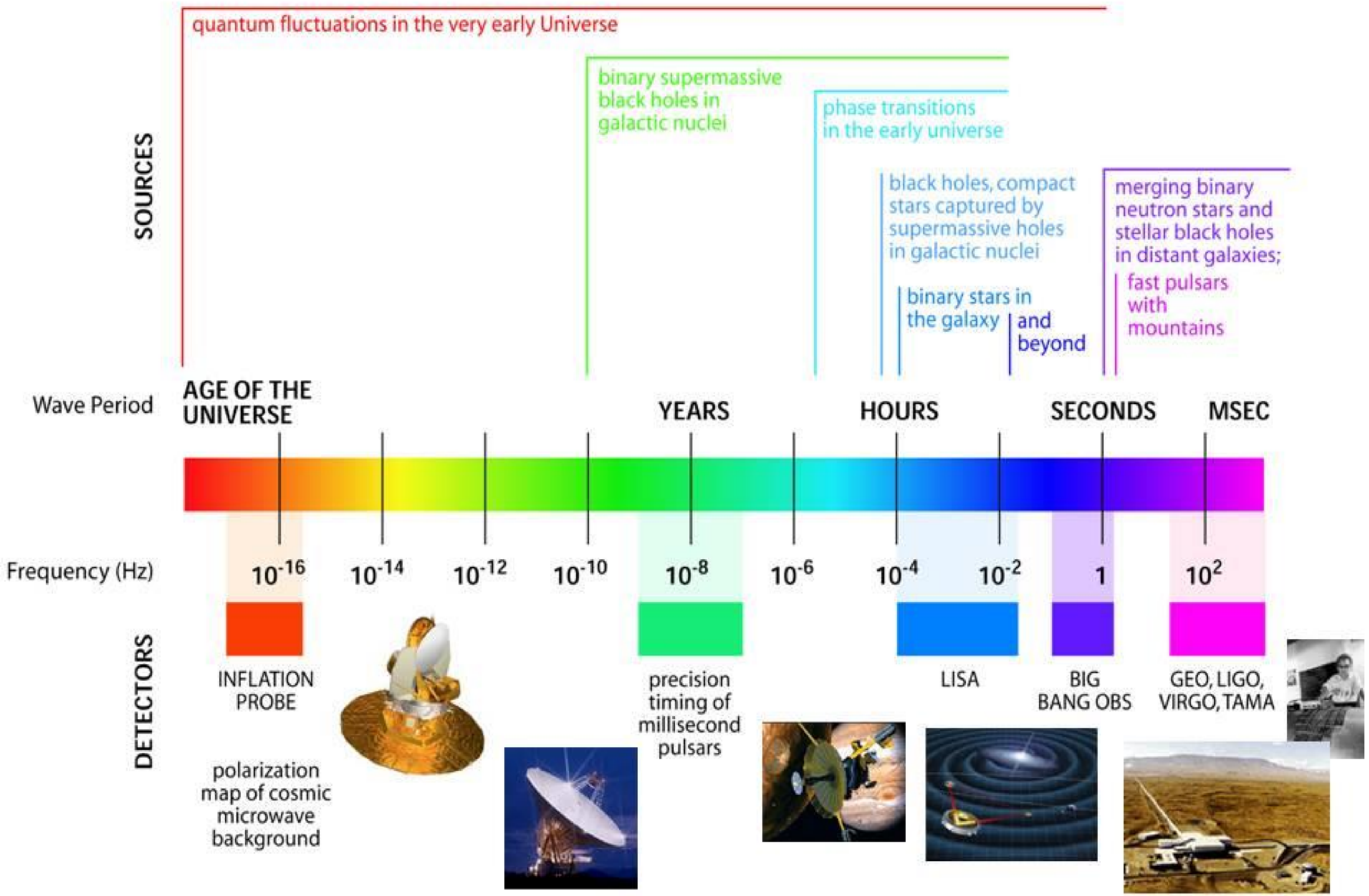
for m=100 GeV

->3 November 2015: DEAP

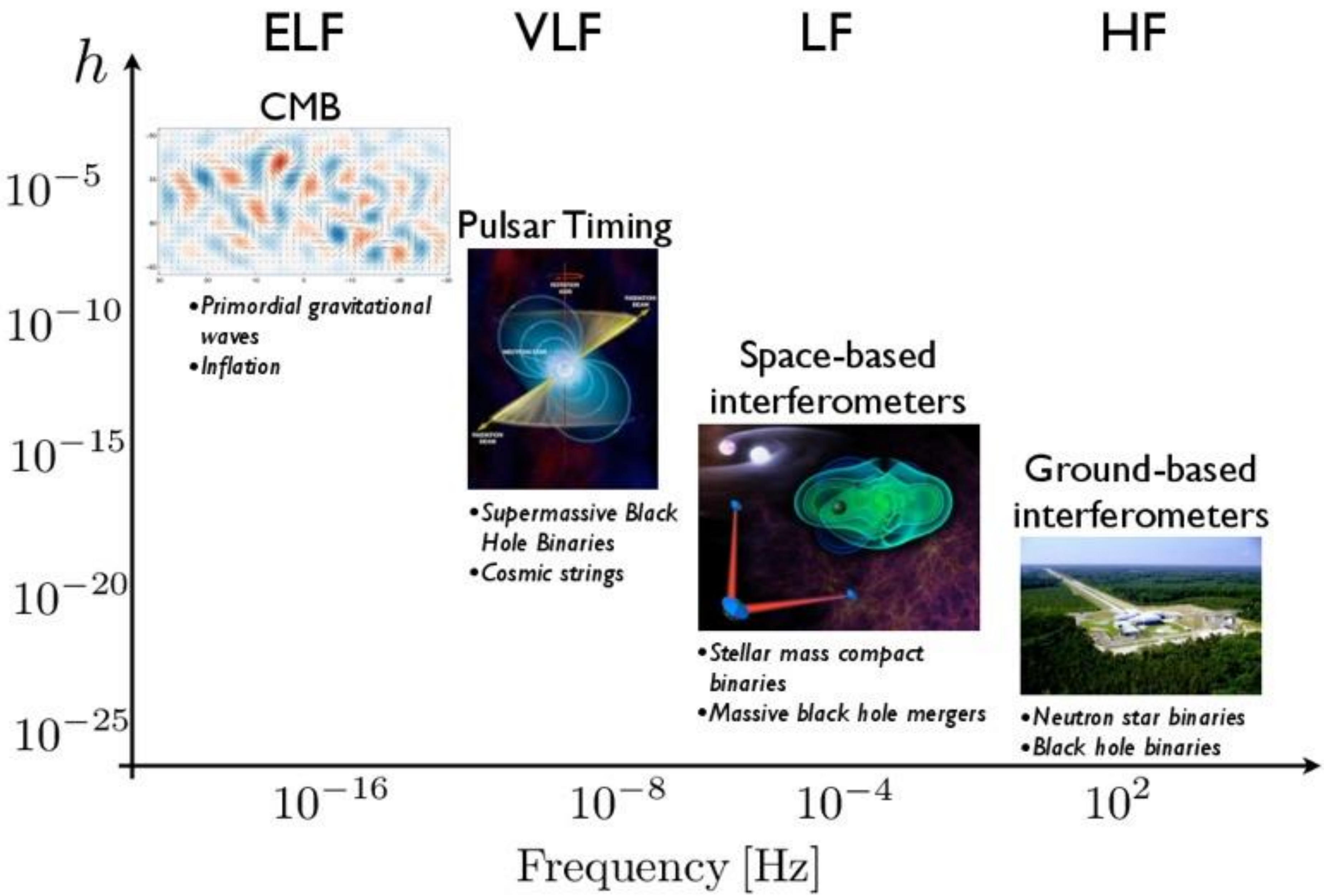
for m = 100 GeV. SNOLab, Canada


Big Bang
quantum-gravity era
Big Bang plus
10^{-43} seconds
inflation
Big Bang plus
10^{-35} seconds?
cosmic microwave background
light
Big Bang plus
380 000 years
gravitational waves
now
Big Bang plus
14 billion years

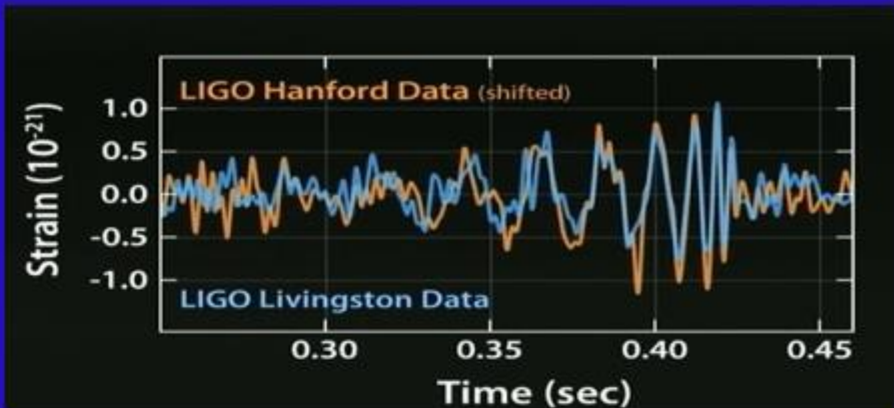
THE GRAVITATIONAL WAVE SPECTRUM

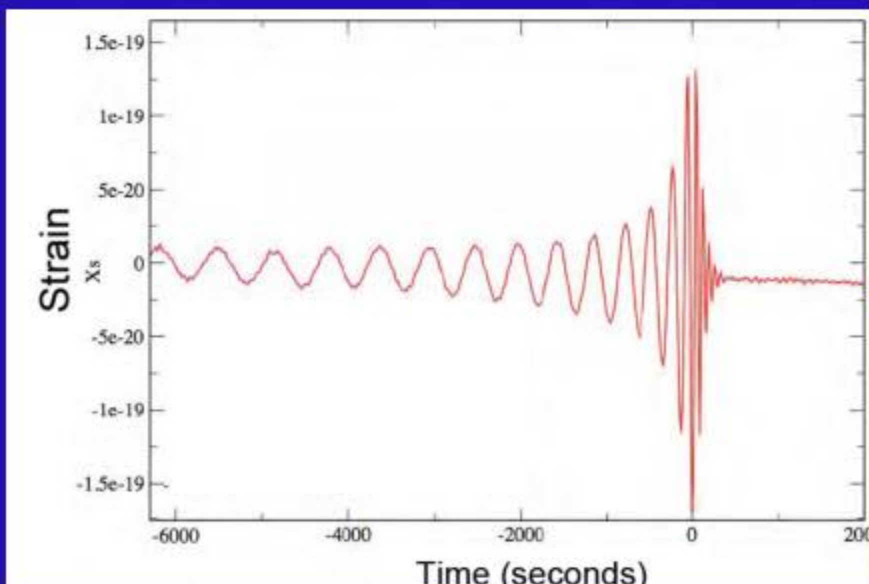


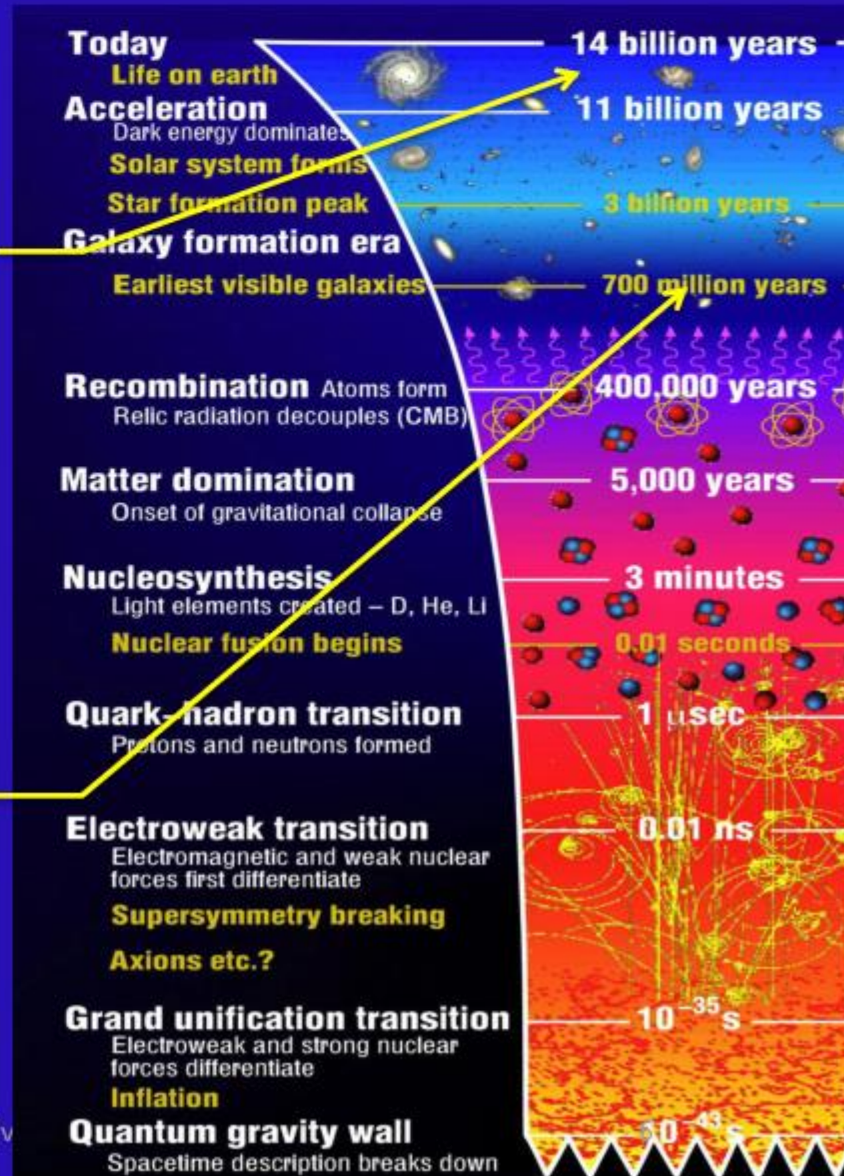
The big picture of gravitational wave astronomy



A deep universe observatory







The constant surface density in dark matter galaxies

Surface density of dark matter (DM) halos $\mu_{0D} \equiv r_0\, \rho_0$,
$r_0 =$ halo core radius, $\rho_0 =$ central density

$\mu_{0D} \simeq 140\, \frac{M_\odot}{\mathrm{pc}^2} = 6400\ \mathrm{MeV}^3 = (18.6\ \mathrm{Mev})^3$ Donato et al.09

Universal value for μ_{0D}: independent of galaxy luminosity for a large number of galactic systems (spirals, dwarf irregular and spheroidals, elliptics) spanning over 14 magnitudes in luminosity and of different Hubble types.

Similar values $\mu_{0D} \simeq 80\, \frac{M_\odot}{\mathrm{pc}^2}$ in interstellar molecular clouds of size r_0 of different type and composition over scales $0.001\, \mathrm{pc} < r_0 < 100$ pc (Larson laws, 1981).

Density profile in Galaxies: $\rho(r) = \rho_0\, F\left(\frac{r}{r_0}\right)\ ,\ F(0) = 1.$

Profiles: $F_{Burkert}(x) = \frac{1}{(1+x)(1+x^2)}\ ,\ F_{Sersic}(x) = e^{-x^{\frac{1}{n}}}\ ,\ x \equiv \frac{r}{r_0}$

Same $1/r^3$ tail as cuspy NFW profile $F_{NFW}(x) = \frac{4}{x\,(1+x)^2}$

Virial theorem plus extensivity of energy $\Longrightarrow \mu_{0D} =$ constant

Virial theorem for self-gravitating systems:

$E = \frac{1}{2}\langle U \rangle = -\langle K \rangle$, $\quad E =$ total energy,

$U =$ potential energy, $K =$ kinetic energy. Therefore,

$$E = -\frac{G}{4}\int \frac{d^3r\, d^3r'}{|\vec{r}-\vec{r}'|}\langle\rho(r)\,\rho(r')\rangle = -\frac{G}{4}\rho_0^2\, r_0^5\int\frac{d^3x\, d^3x'}{|x-x'|}\langle F(x)\, F(x')\rangle$$

Energy divided by the characteristic volume r_0^3 goes as

$$\frac{-E}{r_0^3} \sim G\,\rho_0^2\, r_0^2 = G\,\mu_{0D}^2$$

Energy extensivity requires E/r_0^3 fixed for large values of r_0

$\Longrightarrow \mu_{0D}$ must take the same constant value for all r_0

Estimating $\langle K \rangle$ yields $\langle K \rangle = \frac{1}{2}\int d^3r\,\langle\rho(r)\rangle\,\langle v^2\rangle =$

$= \frac{1}{2}\,\rho_0\, r_0^3\,\langle v^2\rangle\int d^3x\,\langle F(x)\rangle \sim \rho_0\, r_0^3\,\langle v^2\rangle \Longrightarrow \langle v^2\rangle \sim G\,\mu_{0D}\, r_0$

This is true both for molecular clouds and for galaxies.

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 n 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, PRL. 112. 051303 (2014), S. Gariazzo et al. JHEP 1311

Galaxy	$\frac{r_h}{\text{pc}}$	$\frac{\sigma}{\frac{\text{km}}{\text{s}}}$	$\frac{\hbar^{\frac{3}{2}}\sqrt{Q_h}}{(\text{keV})^2}$	$\rho(0)/\frac{M_\odot}{(\text{pc})^3}$	$\frac{M_h}{10^6\ M_\odot}$
Willman 1	19	4	0.85	6.3	0.029
Segue 1	48	4	1.3	2.5	1.93
Leo IV	400	3.3	0.2	.19	200
Canis Venatici II	245	4.6	0.2	0.49	4.8
Coma-Berenices	123	4.6	0.42	2.09	0.14
Leo II	320	6.6	0.093	0.34	36.6
Leo T	170	7.8	0.12	0.79	12.9
Hercules	387	5.1	0.078	0.1	25.1
Carina	424	6.4	0.075	0.15	32.2
Ursa Major I	504	7.6	0.066	0.25	33.2
Draco	305	10.1	0.06	0.5	26.5
Leo I	518	9	0.048	0.22	96
Sculptor	480	9	0.05	0.25	78.8
Boötes I	362	9	0.058	0.38	43.2
Canis Venatici I	1220	7.6	0.037	0.08	344
Sextans	1290	7.1	0.021	0.02	116
Ursa Minor	750	11.5	0.028	0.16	193
Fornax	1730	10.7	0.016	0.053	1750
NGC 185	450	31	0.033	4.09	975
NGC 855	1063	58	0.01	2.64	8340
Small Spiral	5100	40.7	0.0018	0.029	6900
NGC 4478	1890	147	0.003	3.7	6.55×10^4
Medium Spiral	1.9×10^4	76.2	3.7×10^{-4}	0.0076	1.01×10^5
NGC 731	6160	163	9.27×10^{-4}	0.47	2.87×10^5
NGC 3853	5220	198	8.8×10^{-4}	0.77	2.87×10^5
NGC 499	7700	274	5.9×10^{-4}	0.91	1.09×10^6
Large Spiral	5.9×10^4	125	0.96×10^{-4}	2.3×10^{-3}	$1. \times 10^6$

TABLE I: Observed values r_h, σ, $\sqrt{Q_h}$, $\rho(0)$ and M_h covering from ultracompact objects and