The 15th Chalonge Cosmology Colloquium 2011: ‘From Cold Dark Matter to WARM Dark Matter in the Standard Model of the Universe’

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Séminaire du CPPM - Marseille

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The Chalonge School

Starts in 1991 in Erice. 15 Colloquia, 10 Courses and 10 workshops in twenty years in

Erice, Palermo, Madrid, Epernay, Torino, Meudon and Paris.

Opening in 1991 by Subramanian Chandrasekhar.

The 15th Chalonge Cosmology Colloquium 2011: ‘From Cold Dark Matter to WARM Dark Matter in the Standard Model of the Universe’. Lecturers:

Philippe ANDRE, Peter L. BIERMANN, Pasquale BLASI, Daniel BOYANOVSKY, Carlo BURIGANA, Asantha COORAY, Hector DE VEGA, Joanna DUNKLEY, Gerry GILMORE, Ayuki KAMADA, Sasha KASHLINSKY, Alan KOGUT, Anthony LASENBY, Manfred LINDNER, John C. MATHER, Felix MIRABEL, Sinziana PADUROIU, Norma G. SANCHEZ, Alexei SMIRNOV, George SMOOT, Sylvaine TURCK-CHIEZE, Christian WEINHEIMER.

Group Photo 15th Chalonge Colloquium 2011

All lectures are online at http://www.chalonge.obspm.fr/

tandard Cosmological Model: DM + Λ + Baryons + Radiati

- Begins by the inflationary era. Slow-Roll inflation explains horizon and flatness.
- Gravity is described by Einstein's General Relativity.
- Particle Physics described by the Standard Model of Particle Physics: $SU(3) \otimes SU(2) \otimes U(1) =$ qcd+electroweak model.
- Dark matter is non-relativistic during the matter dominated era where structure formation happens. DM is outside the SM of particle physics.
- Dark energy described by the cosmological constant Λ.

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

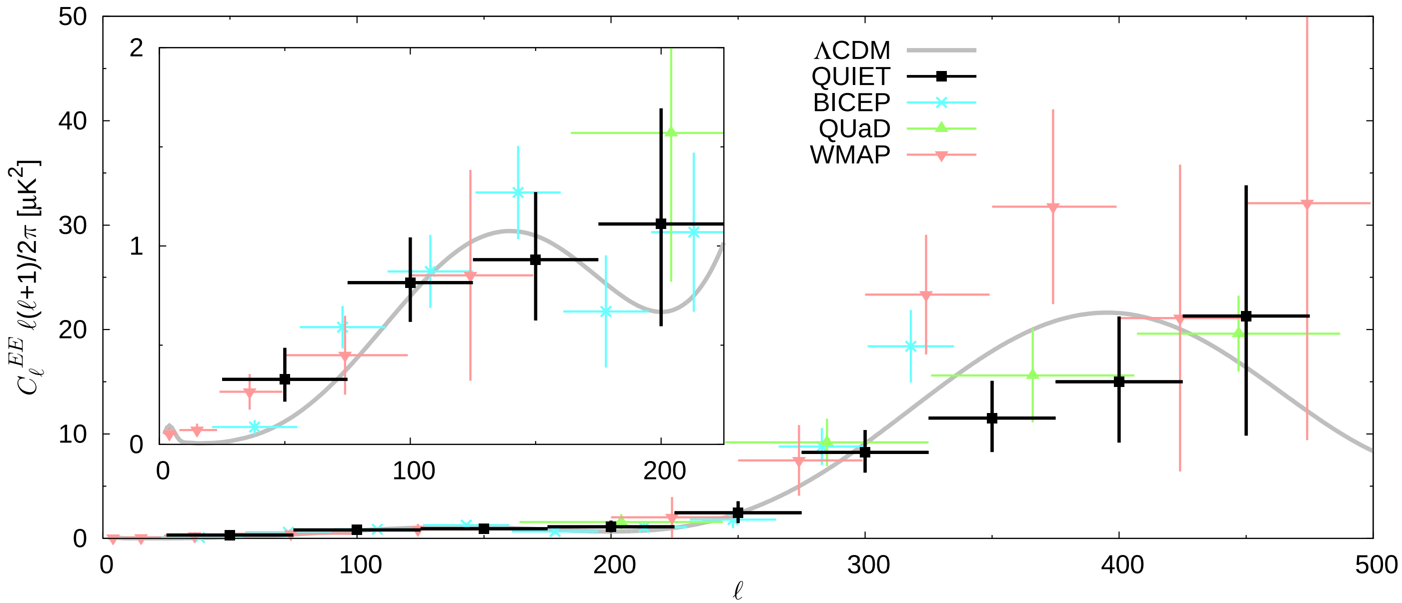
CMB Anisotropies

Lectures by Anthony Lasenby, Carlo Burigana (in behalf of Reno Mandolesi and the Planck collaboration) and Joanna Dunkley:

Interregnum between WMAP and Planck satellites.

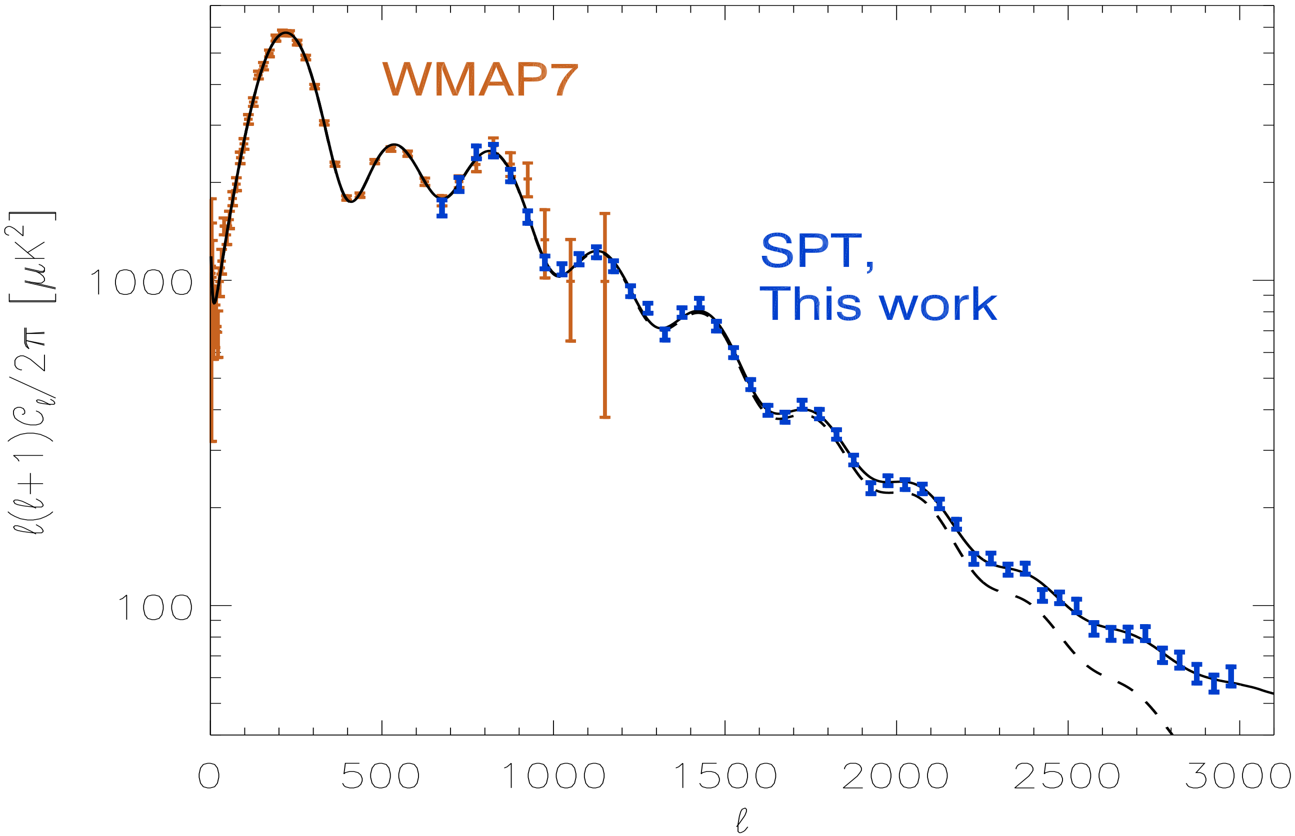
QUIET reports new results on polarization in using *coherent* rather than bolometric techniques arXiv1012.3191.

Confirm the first peak in the EE spectrum first seen in the BICEP experiment

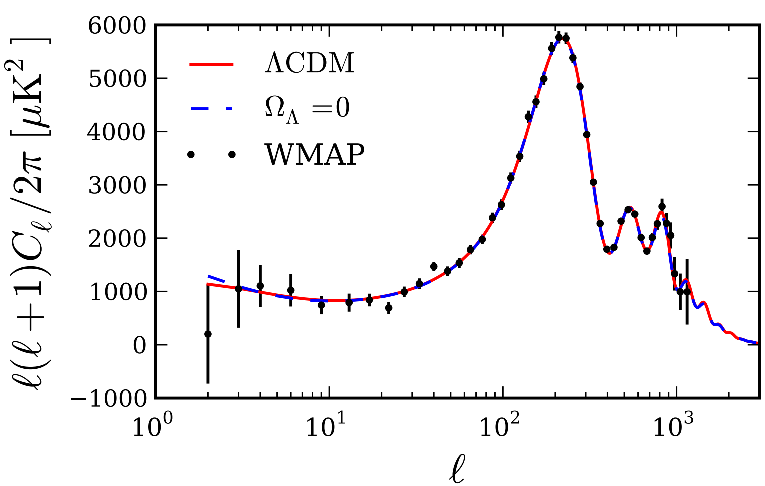


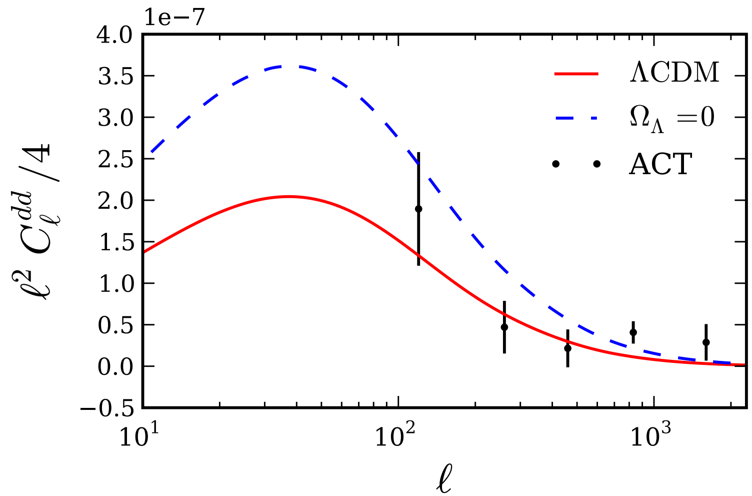
New Results from the South Pole Telescope (SPT)

SPT (arXiv1105.3182): 790 square degrees of sky measured at 150 GHz, and displays a CMB power spectrum in which 9 peaks can now be clearly discerned.



New results from Atacama Cosmology Telescope (ACT)





Two models that are degenerate in CMB temperature power (left) can be distinguished using CMB lensing (right): the curved model with no Dark Energy gives more lensing than the ΛCDM model.

Planck results for the SZ effect in clusters of galaxies

The resolution of Planck for SZ studies (at best $\sim 5'$) is lower than for most ground-based observations, but is compensated for by all-sky coverage, plus a good frequency discrimination.

Amongst the new clusters one turned out, following XMM-Newton confirmation, to be the first supercluster to be detected via the blank-field SZ effect.

Other telescopes have now confirmed some of the other candidates.

Cosmological Data Today

SPT + WMAP7 + H_0 + BAO

$n_s = 0.967 \pm 0.01 \quad , \quad r < 0.17$

$\sigma_8 = 0.793 \pm 0.016 \quad , \quad w = -0.973 \pm 0.063$

$N_{eff} = 3.86 \pm 0.42$

(Recall that $N_{eff} = 3.046$ for three relativistic species).

A fourth relativistic specie? (‘Dark Radiation’?)

A eV scale sterile neutrino?

Evidences for eV scale sterile neutrinos (1-2?) from MiniBooneNE, MINOS, IceCube (?).

BBN is against two eV scale sterile neutrinos but is compatible with one.

The Theory of Inflation

We formulated inflation theory is an effective field theory in the Ginsburg-Landau sense.

D. Boyanovsky, C. Destri, H. J. de Vega, N. G. Sánchez, The Effective Theory of Inflation in the Standard Model of the Universe and the CMB+LSS data analysis (review article), arXiv:0901.0549, Int.J.Mod.Phys.**A 24**, 3669-3864 (2009). Relevant effective theories in physics:

- Ginsburg-Landau theory of superconductivity. It is an effective theory for Cooper pairs. BCS microscopic th.
- The $O(4)$ sigma model for pions, the sigma and photons below 1 GeV. Microscopic theory is QCD: quarks and gluons. $\pi \simeq \bar{q}q \;,\; \sigma \simeq \bar{q}q$.
- The theory of second order phase transitions à la Landau-Kadanoff-Wilson...
- Fermi Theory of Weak Interactions (current-current).

Effective Theory of Inflation: à la Ginsburg-Landau

N efolds since the inflaton exits the horizon till the end of inflation: $N \sim 60$.
In the effective theory of inflation the slow-roll inflaton potential has the universal form:

$V(\phi) = N\; M^4\; w(\chi)\;,\; M =$ energy scale of inflation,
$\chi \equiv \frac{\phi}{\sqrt{N}\; M_{Pl}} =$ dimensionless and slow field. $\chi,\; w(\chi) = \mathcal{O}(1)$
The slow-roll expansion becomes a $1/N$ expansion.

We find in this effective theory of inflation for the adiabatic Scalar Perturbations: $P(k) = |\Delta^{(S)}_{k\; ad}|^2\; k^{n_s - 1}$:

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

for all slow-roll inflation models:

The WMAP7 result: $|\Delta^{(S)}_{k\; ad}| = (0.494 \pm 0.01) \times 10^{-4}$
determines the scale of inflation M (using $N \simeq 60$).

Inflation energy scale M, the spectral index n_s and the ratio

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

The inflation energy scale M turns to be the grand unification energy scale !!

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

We find the scale of inflation without knowing the ratio r of tensor to scalar fluctuations.
(tensor fluctuations = primordial gravitons).

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

χ is the inflaton field at horizon exit.

We obtain the model independent estimates:

$n_s - 1$ and r are of the order $1/N \sim 0.02$,

$dn_s/d\ln k$ is of the order $1/N^2 \sim 0.0003 \Leftarrow$ negligible !!

MCMC Results for double–well inflaton potential

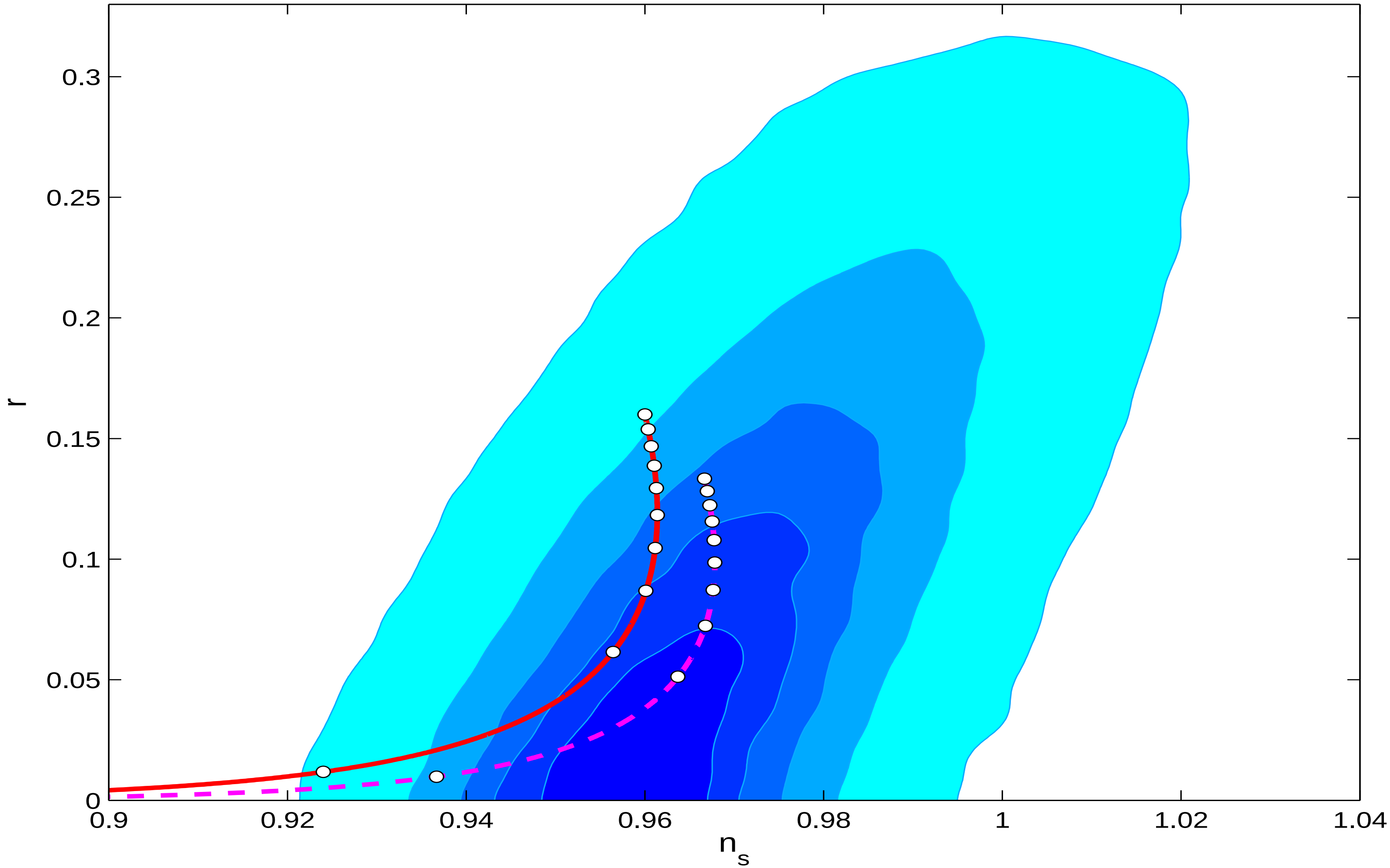
Bounds: $r > 0.023$ (95% CL) , $r > 0.046$ (68% CL)
Most probable values: $n_s \simeq 0.964$, $r \simeq 0.051 \Leftarrow$measurable!!
The most probable double–well inflaton potential has a moderate nonlinearity with the quartic coupling $y \simeq 1.26 \ldots$.
The $\chi \to -\chi$ symmetry is here spontaneously 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, Phys. Rev. D77, 043509 (2008), astro-ph/0703417.

Planck may measure such $r \simeq 0.05$: borderline
C. Burigana, C. Destri, H. J. de Vega, A. Gruppuso, N. Mandolesi, P. Natoli, N. G. Sanchez, Ap J, 724, 588 (2010), arXiv:1003.6108.

MCMC Results for the double–well inflaton potential



Solid line for $N = 50$ and dashed line for $N = 60$
y increases from the uppermost dot $y = 0$

John C. Mather: James Webb Space Telescope

James E. Webb built the Apollo program.

JWST is the most powerful space telescope ever designed, capable of observing the early universe within a few hundred million years of the Big Bang, revealing the formation of galaxies, stars, and planets, and showing the evolution of solar systems like ours.

Under study since 1995, it is a project led by NASA with ESA and CSA major contributions.

6.6 m diameter aperture, passively cooled to below 50 K, Near-IR Camera, Near-IR Spectrograph, near-IR Tunable Filter Imager and Mid-IR Instrument.

Launch in 2018? on an Ariane 5 rocket to a Sun - Earth Lagrange point L_2, 1.5×10^6 km from Earth. Fuel for 10 yr.

http://www.jwst.nasa.gov/

JWST Scientific Objectives:

The end of the dark ages: first light and reionization.

The JWST will address the dark energy and dark matter.

Dark Energy: extend the Hubble measurements of distant supernovae using IR photometry where dust obscuration is less than at visible wavelengths.

Improve the calibration of the Hubble constant,

Extend maps of the dark matter distribution to higher redshift, by observing many more faint and higher redshift galaxies.

The birth of stars and protoplanetary systems.

Planetary systems and the origins of life.

To measure the atmospheric composition of an Earth-like planet and to detect the presence of liquid water.

Dark Matter

DM and Galaxies Lecturers: Peter Biermann, Hector de Vega, Gerry Gilmore, Norma Sanchez.

DM particles can decouple being UR or NR.
They can decouple at or out of thermal equilibrium.

The DM distribution function freezes out at decoupling.

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

$r_{lin} = 57.2 \, \mathrm{kpc} \, \frac{\mathrm{keV}}{m} \left(\frac{100}{g_d}\right)^{\frac{1}{3}} \; .$ $\quad g_d =$ 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 r_{lin} are erased.

For $m \sim$ keV WDM particles $r_{lin} \sim 60$ kpc $\sim$ observed DM core sizes

CDM free streaming scale

For CDM particles with $m \sim 100$ GeV: $r_{lin} \sim 0.1$ pc

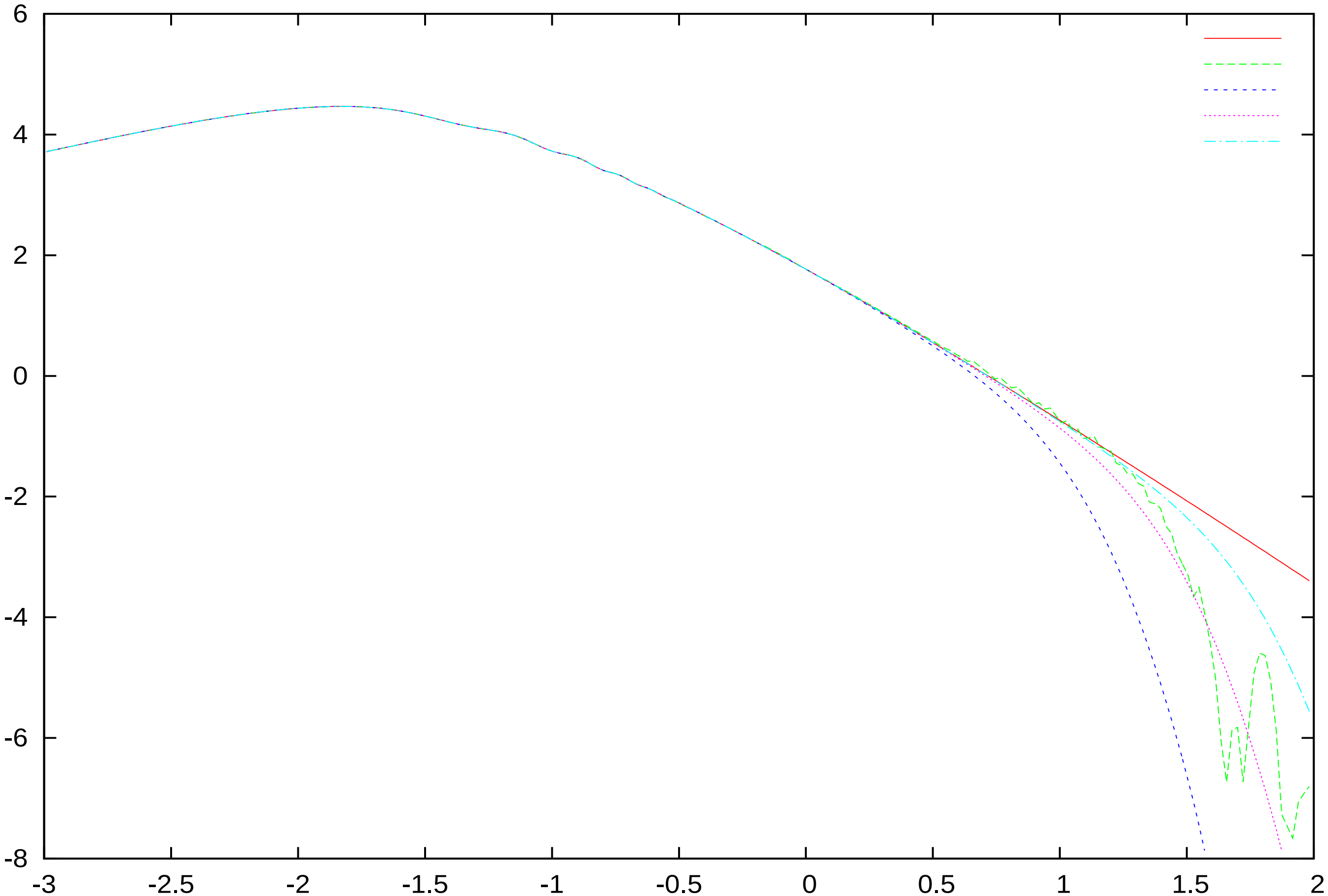
Hence CDM structures keep forming till scales as small as the solar system.

This has been explicitly verified by all CDM simulations but never observed in the sky.

There is over abundance of small structures in CDM (also called the satellite problem).

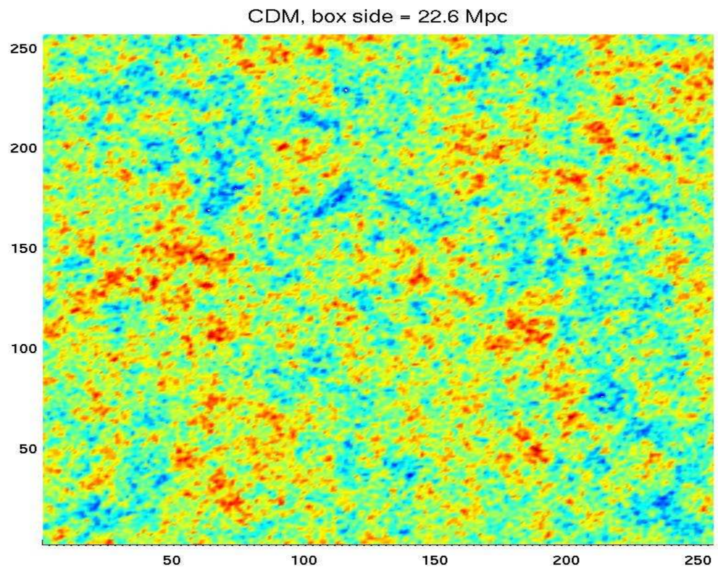
WDM linear fluctuations treated in:
D. Boyanovsky, H. J. de Vega, N. G. Sanchez, Phys. Rev. D 78, 063546 (2008). The dark matter transfer function: free streaming and memory of gravitational clustering.
H. J. de Vega, N. G. Sanchez, arXiv:1111.0290 and .0300 to appear in Phys. Rev D, Cosmological evolution of warm dark matter fluctuations I: Efficient computational framework with Volterra integral equations, II: Solution from small to large scales and keV sterile neutrinos.

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



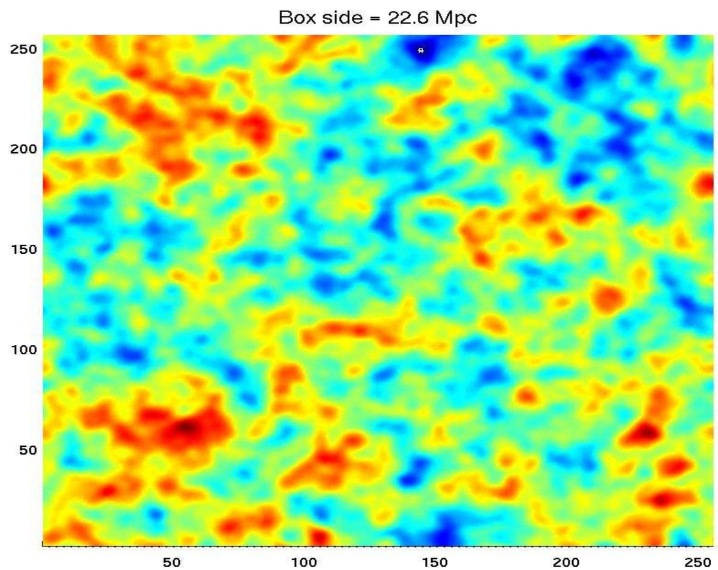
$\log_{10} P(k)$ vs. $\log_{10}[k \text{ Mpc } h]$ for CDM, 1 keV, 2 keV, light-blue 4 keV DM particles decoupling in equil, and 1 keV sterile neutrinos. WDM cuts $P(k)$ on small scales $r \lesssim 100 \, (\text{keV}/m)^{4/3}$ kpc $\simeq$ the free streaming length.

WDM vs. CDM linear fluctuations today



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

WDM:



Galaxy Density Profiles: Cores vs. Cusps

Astronomical observations always find cored profiles for DM dominated galaxies. Selected references:

J. van Eymeren et al. A&A (2009), M. G. Walker, J. Peñarrubia, Ap J (2012). Reviews by de Blok (2010), Salucci & Frigerio Martins (2009).

Galaxy profiles in the linear regime:

core size $\sim$ free streaming length (dV S S, 2010)=

halo radius $r_0 = \begin{cases} 0.05 \text{ pc cusps for CDM (m > GeV).} \\ 50 \text{ kpc cores for WDM (m} \sim \text{keV).} \end{cases}$

N-body simulations $= \begin{cases} \text{CDM} \Rightarrow \text{ cusps (NFW profile).} \\ \text{WDM} \Rightarrow \text{ cores (Burkert profile).} \end{cases}$

DM simulations give a precise value for the concentration $\equiv R_{virial}/r_0$. CDM concentrations disagree with the values needed to fit observed profiles.

The Phase-space density I

All DM physical quantities can be obtained from it in the early universe (before structure formation) as energy density $\rho_{DM}(t)$ and velocity fluctuations $\langle\sigma^2_{DM}(t)\rangle$.

The phase-space density $Q \equiv \rho_{DM}/\sigma^3_{DM}$ is invariant under the cosmological expansion and can only decrease under self-gravity interactions (gravitational clustering).

Early universe value: $Q_{prim} = \rho_{prim}/\sigma^3_{prim} = \frac{3\sqrt{3}}{2\,\pi^2}\; g\; \frac{I_2^{\frac{5}{2}}}{I_4^{\frac{3}{2}}}\; m^4$

I_2 and I_4 are momenta of the DM distribution function.
g number of internal degrees of freedom of the DM particle, $1 \leq g \leq 4$.

During structure formation Q decreases by a factor that we call Z, $(Z > 1)$: $\quad Q_{today} = \frac{1}{Z}\, Q_{prim}$

The Phase-space density $Q = \rho/\sigma^3$ and its decrease factor Z

The phase-space density today Q_{today} follows observing dwarf spheroidal satellite galaxies of the Milky Way (dSphs) as well as spiral galaxies. Its value is galaxy dependent.

For dSphs $Q_{today} \sim \; (0.18 \text{ keV})^4$ Gilmore et al. 07/08.

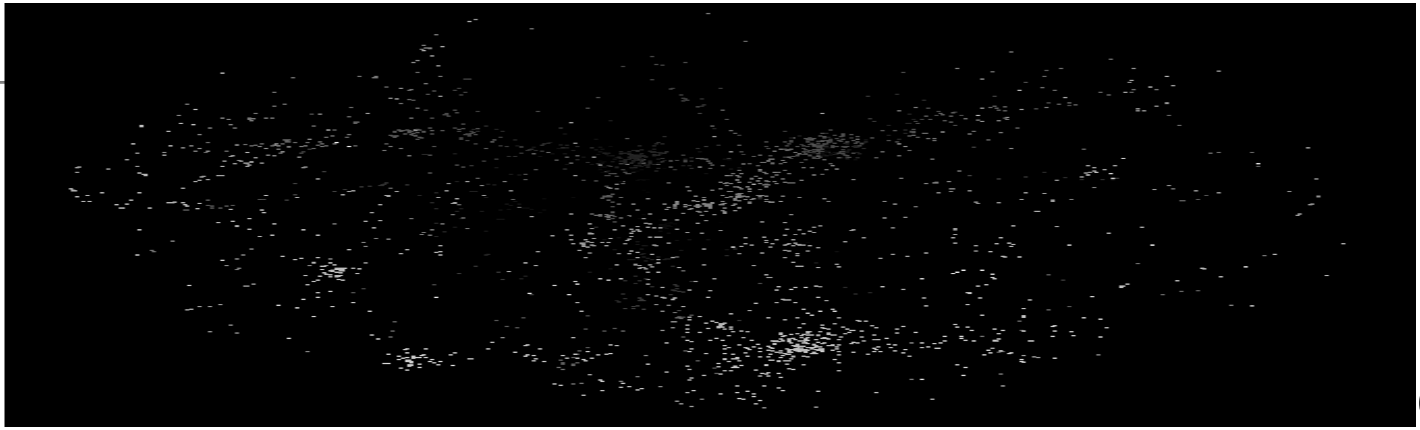
The spherical model gives $Z \simeq 41000$ and N-body simulations indicate: $10000 > Z > 1$. Z is galaxy dependent.

As a consequence m is in the keV scale:1keV$\lesssim m \lesssim 10$keV. H. J. de Vega, N. G. Sanchez, MNRAS (2010)

This is true both for DM decoupling in or out of equilibrium, bosons or fermions.

It is independent of the particle physics model.

ΛCDM and ΛWDM simulations vs. astronomical observations

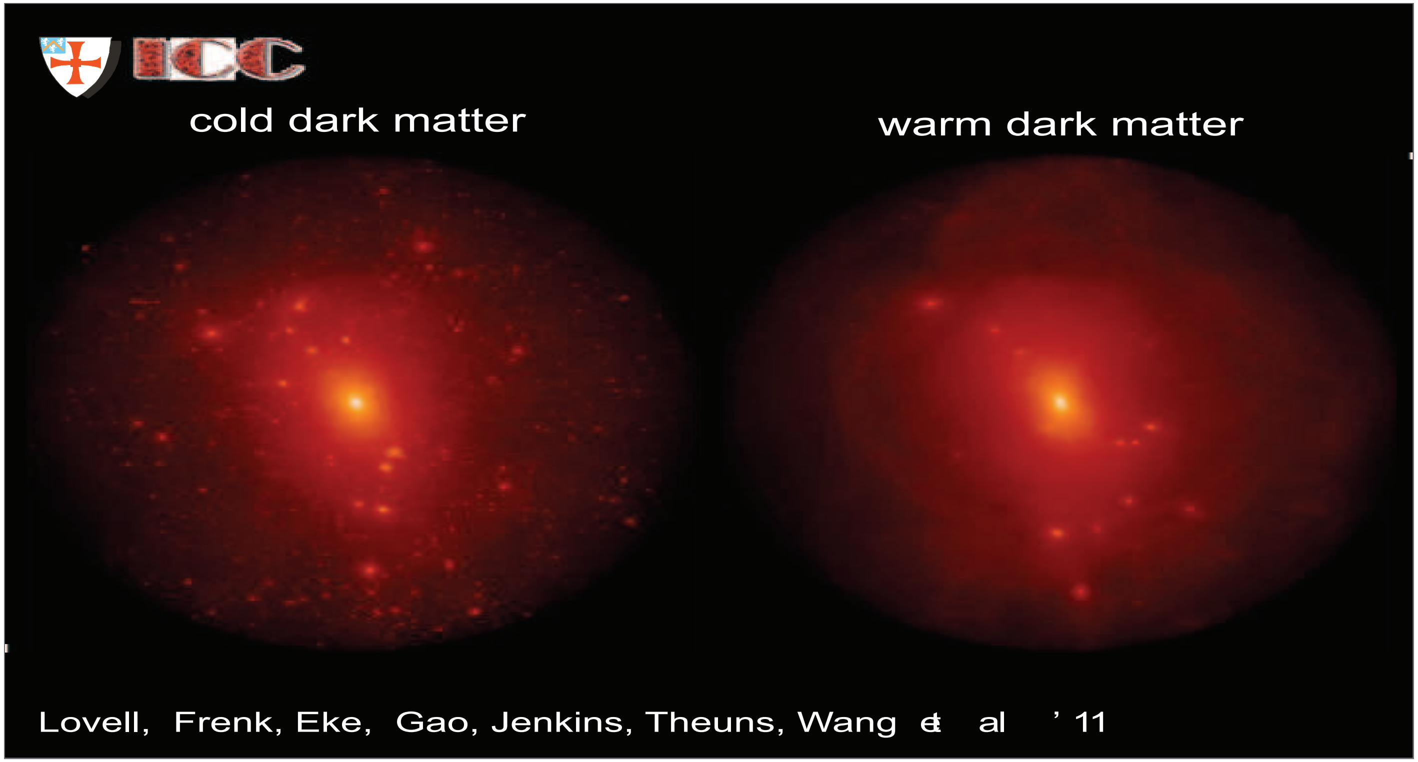


ΛCDM

observations

1keV WDM

N-body WDM Simulations



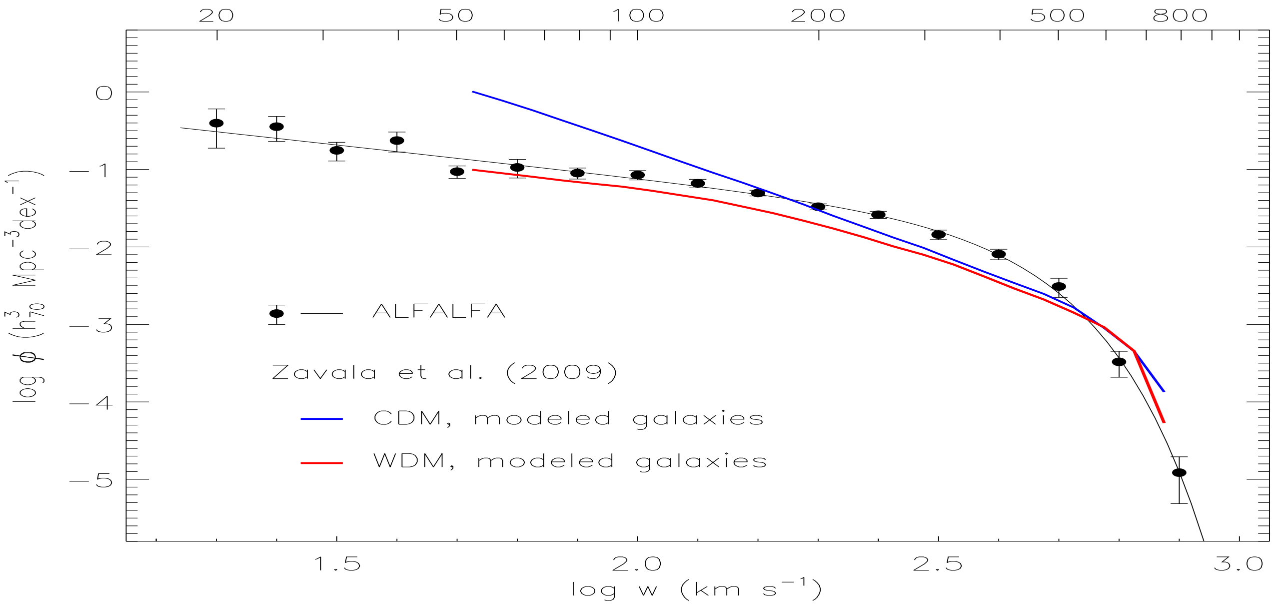
Wednesday, 15 June 2011

WDM subhalos are less concentrated than CDM subhalos.

WDM subhalos have the right concentration to host the bright Milky Way satellites.

Lovell et al. arXiv:1104.2929

Velocity widths in galaxies



Velocity widths in galaxies from 21cm HI surveys. ALFALFA survey clearly favours WDM over CDM. (Papastergis et al. ApJ 2011, Zavala et al. ApJ 2009).

Notice that the WDM red curve is for $m = 1$ keV WDM particle decoupling at thermal equilibrium.

The 1 keV WDM curve falls somehow below the data suggesting a slightly larger WDM particle mass.

WDM properties

WDM is characterized by

- its initial power spectrum cutted off for scales below ~ 50 kpc. Thus, structures are not formed in WDM for scales below ~ 50 kpc.
- its initial velocity dispersion which is non-negligible here contrary to CDM.

N-body simulations show that structure formation happens later in WDM than in CDM since the non-linear regime starts later in WDM than in CDM.

N-body simulations are technically more difficult in WDM than in CDM.

Structure formation is hierarchical in CDM.

WDM simulations show in addition top-hat structure formation at large scales and low densities but hierarchical structure formation remains dominant.

Particle physics candidates for DM

No particle in the Standard Model of particle physics (SM) can play the role of DM.

Many extensions of the SM can be envisaged to include a DM particle with mass in the keV scale and weakly enough coupled to the Standard Model particles to fulfill all particle physics experimental constraints.

Main candidates in the keV mass scale: sterile neutrinos, gravitinos, light neutralino, majoron ...

Particle physics motivations for sterile neutrinos:

There are both left and right handed quarks
(with respect to the chirality).

It is natural to have right handed neutrinos ν_R besides the known left-handed neutrino. Quark-lepton similarity.

Sterile Neutrinos

Mixing angle: $\theta \sim 10^{-4}$ is appropriate to produce enough sterile neutrinos accounting for the observed DM.

Smallness of θ makes sterile neutrinos difficult to detect.

Precise measure of nucleus recoil in tritium beta decay:
$^3H_1 \Longrightarrow {}^3He_2 + e^- + \bar{\nu}$ can show the presence of a sterile instead of the active $\bar{\nu}$ in the decay products.

Rhenium 187 beta decay gives $\theta < 0.095$ for 1 keV steriles [Galeazzi et al. PRL, 86, 1978 (2001)].
Available energy: $Q({}^{187}Re) = 2.47$ keV, $Q({}^3H_1) = 18.6$ keV.

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.

Sterile neutrino models

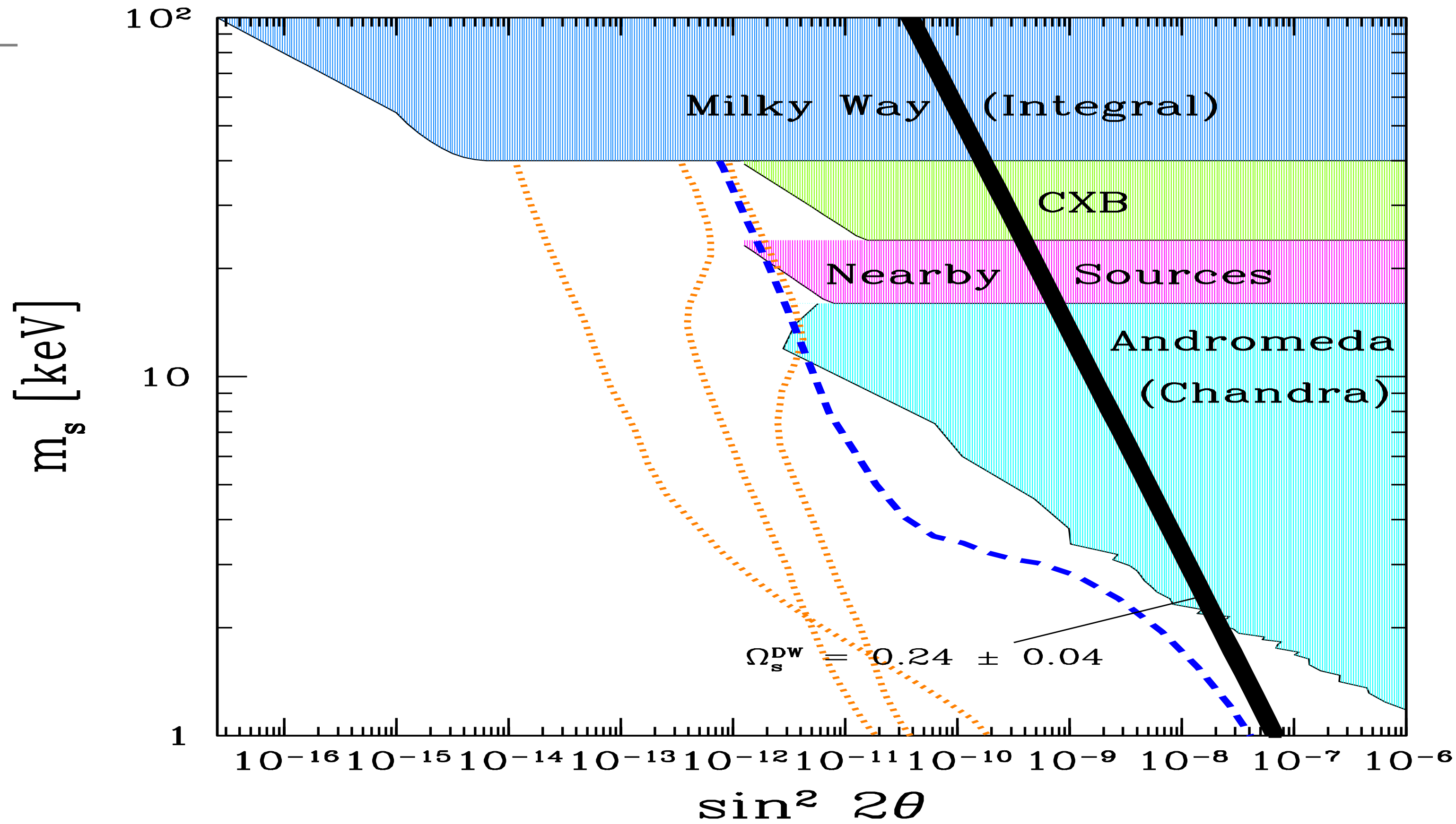
Sterile neutrinos: named by Bruno Pontecorvo (1968).

- DW: Dodelson-Widrow model (1994) sterile neutrinos produced by non-resonant mixing from active neutrinos.
- Shi-Fuller model (1998) sterile neutrinos produced by resonant mixing from active neutrinos.
- χ-model (1981)-(2006) sterile neutrinos produced by a Yukawa coupling from a real scalar χ.
- Further models must reproduce $\bar{\rho}_{DM}$, galaxy and structure formation and be consistent with particle physics experiments.

WDM particles in different models behave just as if their masses were different:

$$m_{DW} \simeq 4.4\,(m_{Thermal})^{4/3}, \; m_{DW} \simeq 1.5\,m_{SF}, \; m_{SF} \simeq 3\,m_{\chi}.$$

Constraints on the sterile neutrino mass and mixing angle



Dashed = Shi-Fuller model. Dotted = Dodelson-Widrow.
Allowed sterile neutrino region in the right lower corner.
Galaxy analysis faulty (use of unrealistic cusped NFW profiles for DM)
Inaccurate treatment of the Boltzmann-Vlasov equation.

Further Experiments to detect Sterile Neutrinos

Lyα forest observations give limits on the sterile ν mass. However, it is the most sensitive method to the difficult-to-characterize non-linear growth of baryonic and DM structures. As a result, there are significant discrepancies between the reported mass lower limits.

Supernovae: θ unconstrained, $1 < m < 10$ keV (G. Raffelt & S. Zhou, PRD 2011).

CMB: WDM decay distorts the blackbody CMB specturum. The projected PIXIE satellite mission (A. Kogut et al.) can measure WDM sterile neutrino mass.

Rhenium and Tritium beta decay (MARE, KATRIN). Theoretical analysis: H J de V, O. Moreno, E. Moya de Guerra, M. Ramón Medrano, N. Sánchez, (2011).

Sterile Neutrinos may be observed in electron capture (EC) as in ^{163}Ho $\rightarrow$ ^{163}Dy, MARE experiment (Nuccioti et al.)

Cosmic Rays and GRB Lectures

Peter BIERMANN Astrophysical Warm Dark Matter
Pasquale BLASI: Astrophysical Origin of the Positron Excess in Cosmic Rays

Positrons are produced by many astrophysical ways: radioactive decays in supernova remnants, pulsar magnetospheres (cascade multiplication in intense magnetic fields), secondary products of hadronic interactions, $\mu^{\pm} \rightarrow e^{\pm} + \nu_e + \nu_\mu$ and $\gamma + \gamma \rightarrow e^{+} + e^{-}$.

Diffuse-convection processes in shock acceleration. Blast waves in pulsar wind nebulae (Fokker-Planck). Taking all that into account may very well explain the Fermi-Lat and Pamela data.

George SMOOT: Early Light from Gamma Ray Bursts UFFO-Pathfinder mission Russia/Korea et al. Satellite to study Short GRB to be launched in Russia in 2012.

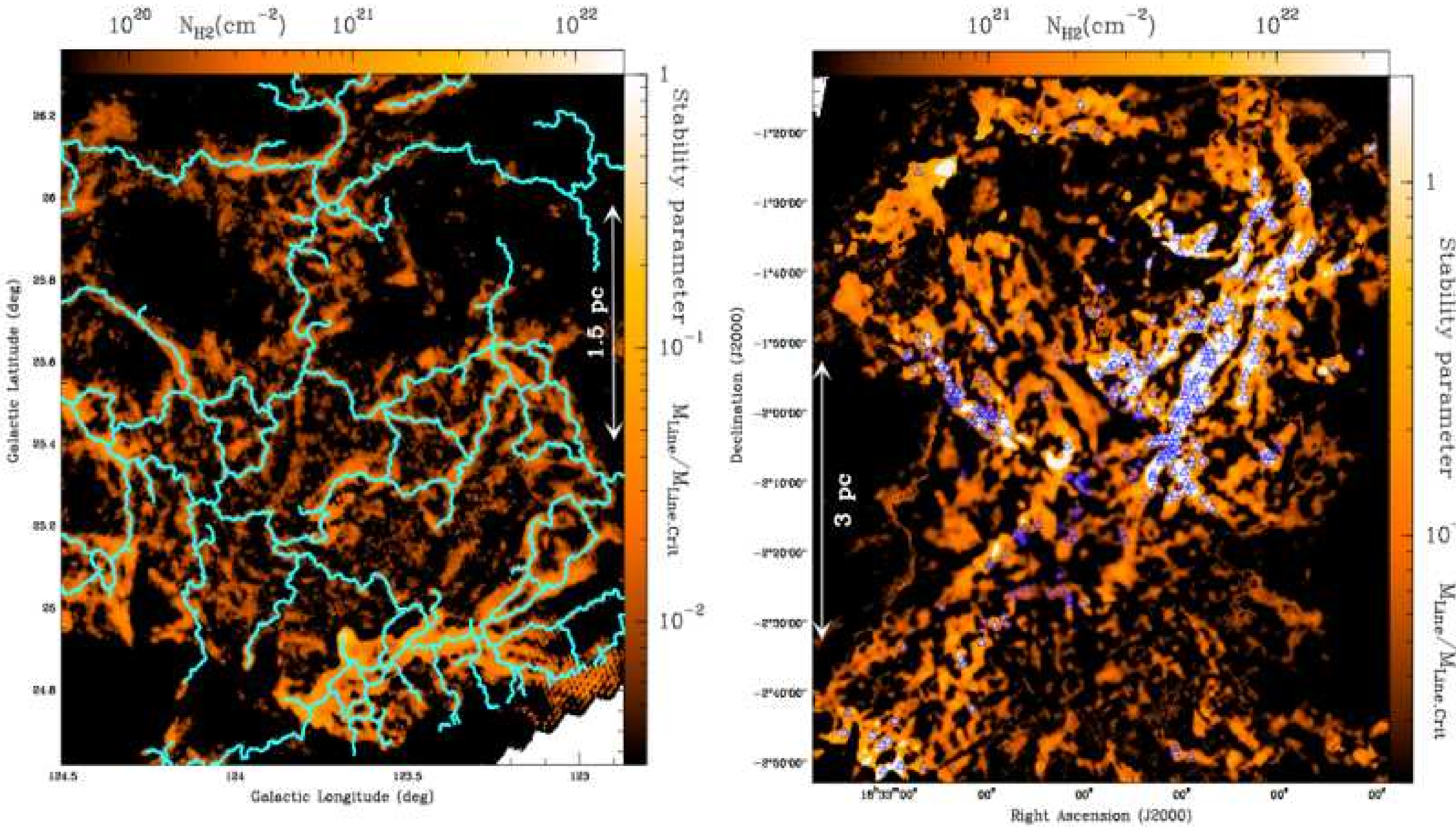
Herschel Results

Infrared Sky: Asantha Cooray,
From the filamentary structure of the ISM to prestellar cores to the IMF: Philippe André.

Images suggest an intimate connection between the filamentary structure of the ISM and the formation process of dense cloud cores.
Core formation occurs in two steps. 1) large-scale MHD turbulence generates a network of filaments,
2) the densest filaments fragment into prestellar cores by gravitational instability.
Herschel results confirm a close relationship between the prestellar core mass function and the stellar IMF.

Star formation threshold at a gas surface density $\Sigma_{\rm gas}^{\rm th} \sim 130 \; M_\odot \, {\rm pc}^{-2}$

Same value for the surface density in DM galaxies !!



10^20 N_H2(cm^-2) 10^21 10^22
Stability parameter
1
10^-1
10^-2
M_Line/M_Line,Crit
1.5 pc
Galactic Latitude (deg)
Galactic Longitude (deg)
124.5
124
123.5
123
10^21 N_H2(cm^-2) 10^22
3 pc
Declination (J2000)
Right Ascension (J2000)

Summary: keV scale DM particles

- Reproduce the phase-space density observed in dwarf satellite galaxies and spiral galaxies (dV S 2009).
- Provide cored universal galaxy profiles in agreement with observations (dV S 2009,dV S S 2010).
- The galaxy surface density $\mu_0 \equiv \rho_0 \, r_0$ is universal up to $\pm 10\%$ according to the observations. Its value $\mu_0 \simeq (18 \text{ MeV})^3$ is reproduced by WDM (dV S S 2010). WIMPS simulations give 1000 times the observed value of μ_0 (Hoffman et al. ApJ 2007).
- Alleviate the satellite problem which appears when wimps are used (Avila-Reese et al. 2000, Götz & Sommer-Larsen 2002, Markovic et al. 2011)
- Alleviate the voids problem which appears when wimps are used (Tikhonov et al. MNRAS 2009).

Summary: keV scale DM particles

- All direct searches of DM particles look for $m \gtrsim 1$ GeV. DM mass in the keV scale explains why nothing has been found ... e^+ and $\bar{p}$ excess in cosmic rays may be explained by astrophysics: P. L. Biermann et al. PRL (2009), P. Blasi, P. D. Serpico PRL (2009).
- Velocity widths in galaxies from 21cm HI surveys. ALFALFA survey clearly favours WDM over CDM. Papastergis et al. ApJ 2011, Zavala et al. ApJ 2009
- Combining theoretical evolution of fluctuations through the Boltzmann-Vlasov equation with galaxy data points to a DM particle mass 3 - 10 keV. The keV mass scale holds independently of the DM particle physics model.
- Highlights and conclusions of the Chalonge Meudon Workshop 2011: Warm dark matter in the galaxies: Theoretical and Observational Progresses. H. J. de Vega, N. G. Sanchez, arXiv:1109.3187

Future Perspectives

DM properties from galaxy observations.

Chandra, Suzaku X-ray data: keV mass DM decay?

Sun models well reproduce the sun's chemical composition but not the heliosismology (Asplund et al. 2009).
Can DM inside the Sun help to explain the discrepancy?

Nature of Dark Matter? 83% of the matter in the universe. WDM particles are strongly favoured $m_{DM} \sim$ keV. Sterile neutrinos ? Other particle in the keV mass scale?

Precision determination of DM properties (mass, T_d, nature) from better galaxy data combined with theory (Boltzmann-Vlasov and simulations).

Extensive WDM N-body simulations showing halo cores, density profiles, galaxy formation and evolution

Bounds from MARE on sterile neutrinos mass and θ.
Could KATRIN join the search of sterile neutrinos?

To decipher the nature of DM we need to combine efforts in cosmology, astrophysics, nuclear and particle physics

THANK YOU VERY MUCH

FOR YOUR ATTENTION!!

CHALONGE PROGRAMME OF THE YEAR 2012

* * * * * Support to the James Webb Space Telescope * * * *

Chalonge Meudon Workshop 2012:

"WARM DARK MATTER GALAXY FORMATION IN AGREEMENT WITH OBSERVATIONS"

Meudon historic Castle-CIAS building, Observatoire de Paris at Meudon. Dates: 6, 7 and 8 JUNE 2012.

http://www.chalonge.obspm.fr/Cias Meudon2012.html

16th Paris Cosmology Colloquium 2012

"THE NEW STANDARD MODEL OF THE UNIVERSE: LAMBDA WARM DARK MATTER. THEORY AND OBSERVATIONS"

Paris, Observatoire de Paris, in the Historic Perrault building

Dates: 25, 26, 27 JULY 2012

URL: http://www.chalonge.obspm.fr/colloque2012.html

Galaxy Formation and Evolution

Galaxies naturally grow through merging in CDM models.

Observations show that galaxy mergers are rare ($< 10\%$).

Galaxies often exhibit baryonic matter disks that CDM+baryon models cannot explain without mergers. (J. Kormendy, R. Bender et al. ApJ 2010 and many refs.).

On the other hand CDM generically produces dark disks. No dark disk in the Milky Way (Moni Bidin et al. ApJ 2010).

Galaxy formation within CDM models suffers of serious discrepancies with observations.

WDM simulations are urgently needed.

WDM simulations at present: A. Kamada et al. (IPMU, Tokyo), M. Lovell et al. (Durham), K. Markovic et al. (Munich), S. Paduroiu et al. (Geneva), A. Schneider et al. (Zurich), CLUES collaboration (Berlin-Madrid-Jerusalem), E. Polisensky et al. (Maryland), N. Menci et al. (Roma).