Constrained Local UniversE Simulations
The CLUES-project

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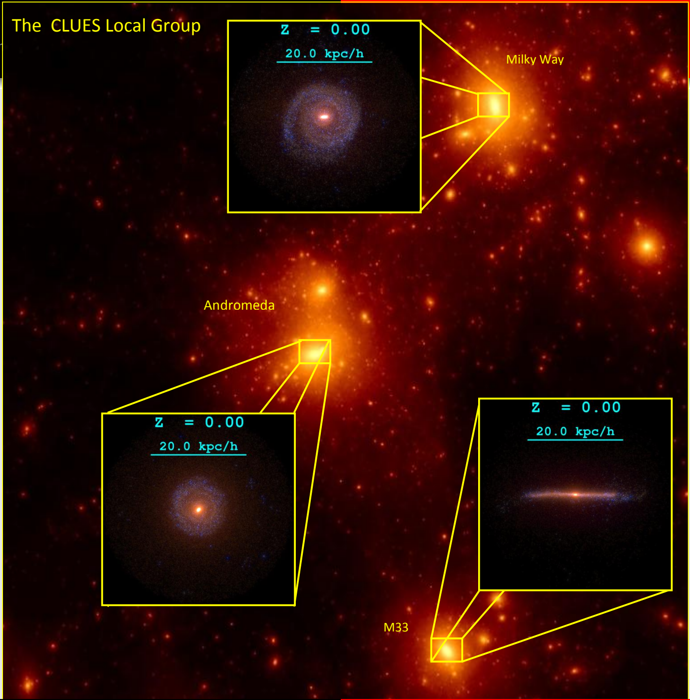
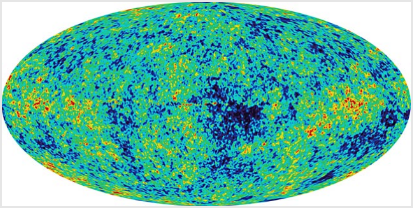
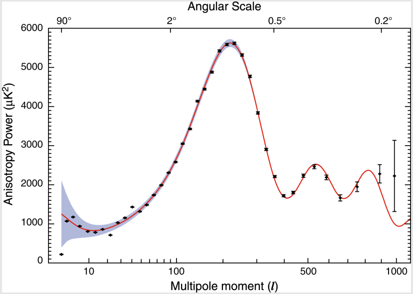

The CLUES Local Group
Z = 0.00
20.0 kpc/h
Milky Way
Andromeda
Z = 0.00
20.0 kpc/h
Z = 0.00
20.0 kpc/h
M33

CLUES collaborators

- Gustavo Yepes (UAM, Madrid)
- Yehuda Hoffman (HU, Jerusalem)
- Anatoly Klypin (NMSU, Las Cruces)
- Matthias Steinmetz (AIP, Potsdam)
- Helene Courtois (IPNL, Lyon)
- Brent Tully (IFA, Honolulu)
- Noam Libeskind (AIP, Potsdam)
- Antonio Cuesta (CSIC, Granada)
- Jesus Zavala (MPA, Garching)
- Anton Tikhonov (St. Petersburg)
- Kristin Riebe (AIP, Potsdam)
- and many more (see http://www.clues-project.org)

Cosmic Microwave Background (CMB) radiation





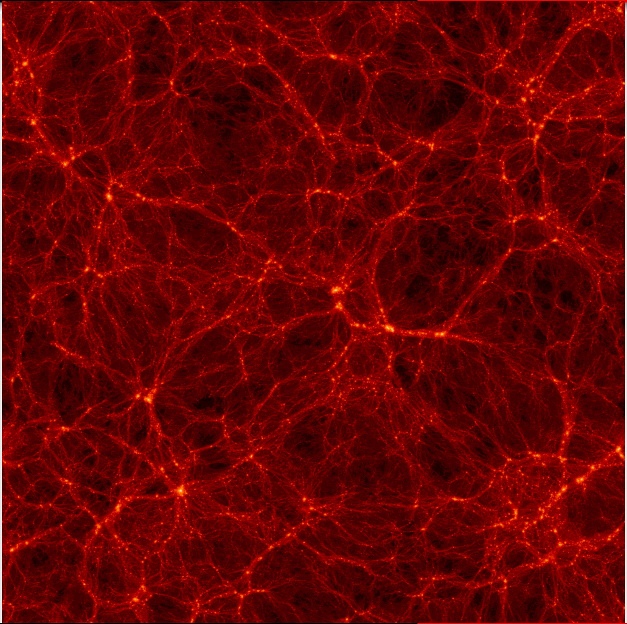
The first structures 13 Gigayears ago.
Their non-linear evolution is studied by cosmological simulations.

Ingredients of simulations

- Dark Energy (74 %)
- Dark Matter (21%)
- Baryons (5%)
  - Computational very expensive
  - "sub-grid" physics not (yet) well modelled
    - star formation
    - chemical evolution
    - formation of super-massive black holes and their influence on galaxies
    - magnetic fields
    - ...
  - Post-processing of DM simulations (semianalytical models)

DM only simulations

- Post-processing of large DM simulations
  - large volumes (good statistics, mock catalogues)
  - high resolution (billions of DM particles)

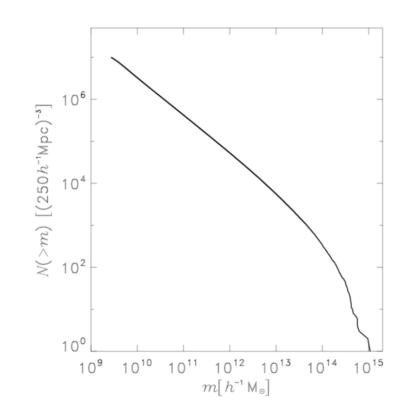


2048^3
$250 h^{-1}\mathrm{Mpc}$
WMAP5

B
o
l
s
h
o
i


3.9 Mpc/h Bolshoi

Bolshoi - mass function



- large samples of different objects
- different environments
- galaxies (SAM) available
  Jaime Forero

Limitations of present day simulations

- Representative volume ($> 500h^{-1}\mathrm{Mpc}$) $\Longleftrightarrow$ desired resolution ($< 0.1h^{-1}\mathrm{kpc}$) $\Longrightarrow$ impossible on present computers
- Mass range ($10^8 ... 10^{15} h^{-1}\mathrm{M}_\odot$) $\Longleftrightarrow$ mass resolution (> 1000 particles) $\Longrightarrow$ impossible on present computers

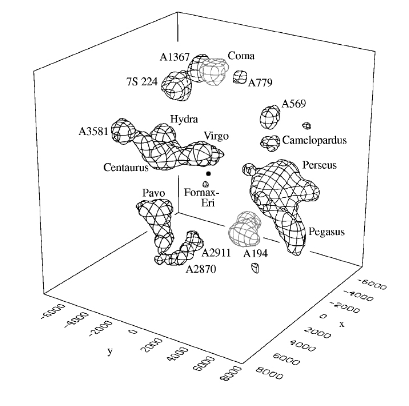
- $\Longrightarrow$ simulate a smaller volume representative for the neighbourhood of Milky Way

CLUES

Constrained Local Universe Simulations

Why are we interested in constrained simulations?

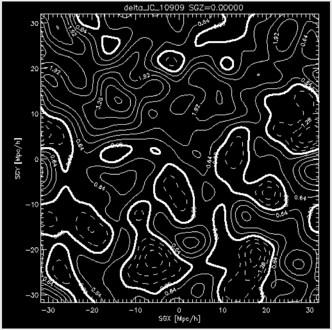
The local neighbourhood of the Milky Way is the most well known piece of the universe. Thus it is an ideal place to test on small scales models of structure formation against observations.
However, the local universe is not a representative part of the universe.

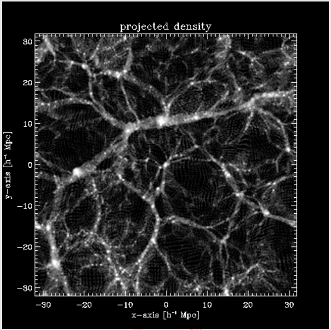


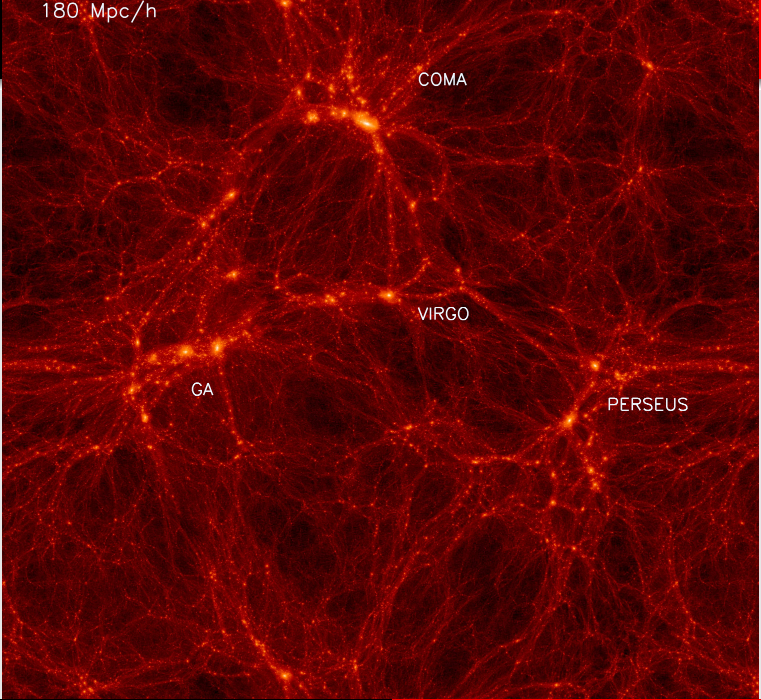
Hudson (1993)

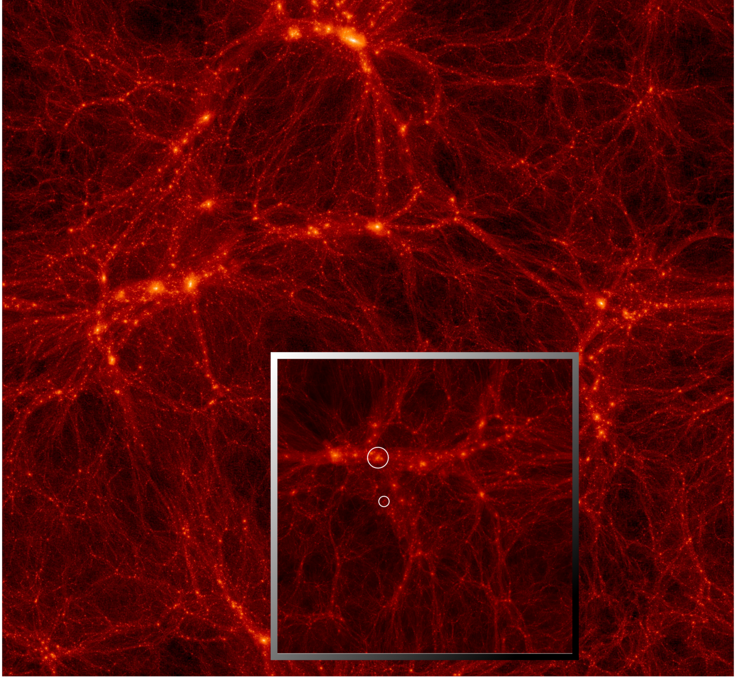
Observational data and constraints

- constraining Gaussian random fields (Hoffman & Ribak, 1991)
- radial velocity field (MARK III, Willick et al., 1997, Tonry 2001, Karachentsev 2004)
- nearby cluster positions (Reiprich & Böhringer, 2002)






180 Mpc/h
COMA
VIRGO
GA
PERSEUS



$160h^{-1}\mathrm{Mpc}$

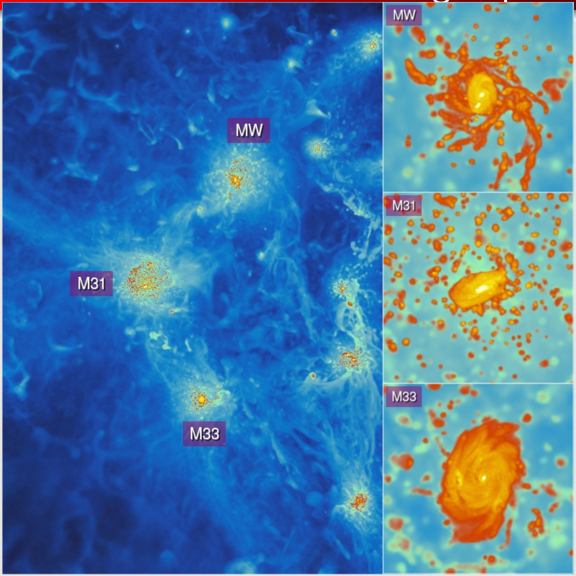
$64h^{-1}\mathrm{Mpc}$

The Local Group simulations

Local Group simulations

- box $64h^{-1}\mathrm{Mpc}$ constrained simulation
- $r = 2h^{-1}\mathrm{Mpc}$ sphere contains:
- Local Group (MW, M33, M31) 4096^3 particles
  - mass resolution DM: $2.1 \times 10^5 h^{-1}\mathrm{M}_\odot$
  - mass resolution gas: $4.4 \times 10^4 h^{-1}\mathrm{M}_\odot$
  - force resolution: $0.15h^{-1}\mathrm{kpc}$

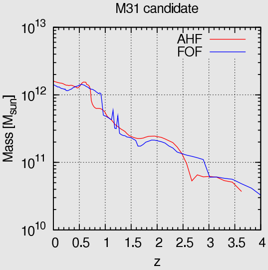
Gas distribution in the local group

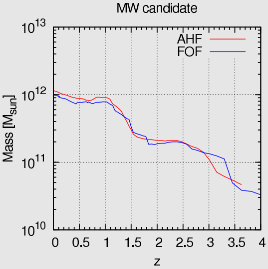


flying to M33

Kristin Riebe

Evolution of M31 and MW



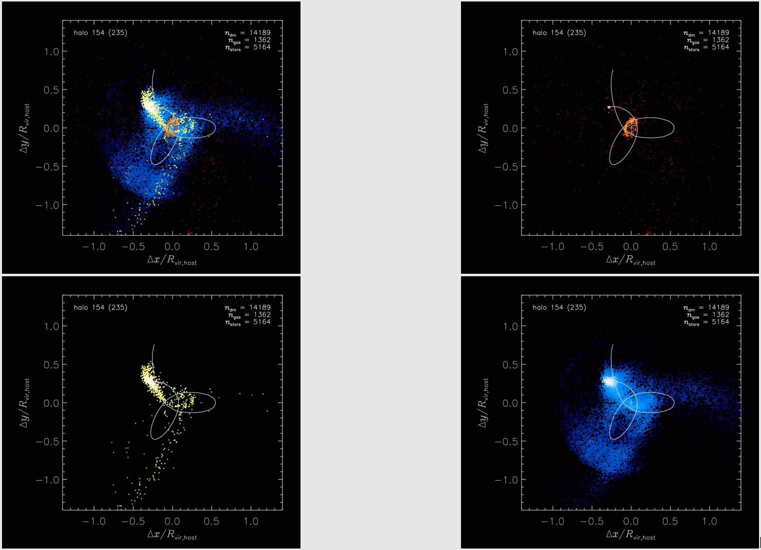


infall of M31 satellites

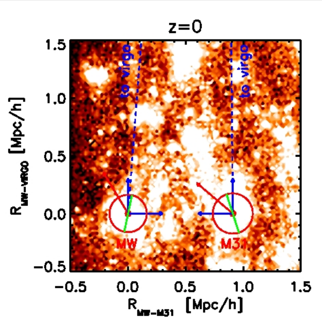
mass accretion histories of the dark matter halos hosting the Milky Way and M31

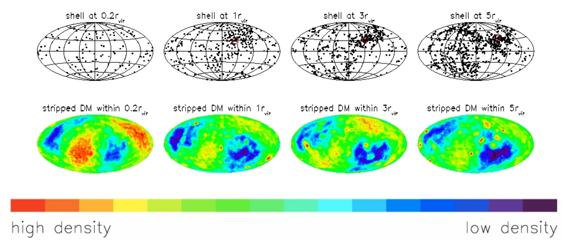
Steffen Knollmann

Tidal streams of a satellite (infall at $z = 0.845$)



Preferential infall

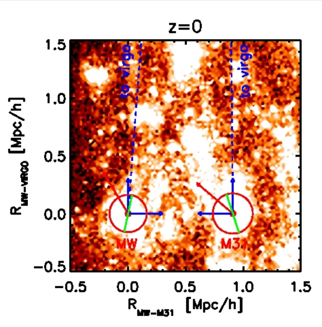


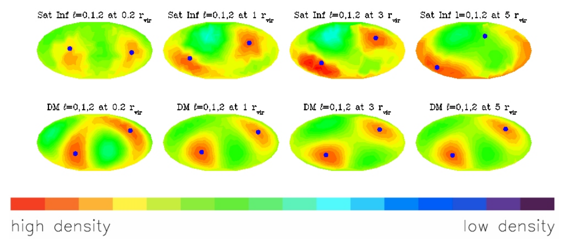


Satellite infall and stripped DM density

Libeskind et al. (2010)

Preferential infall





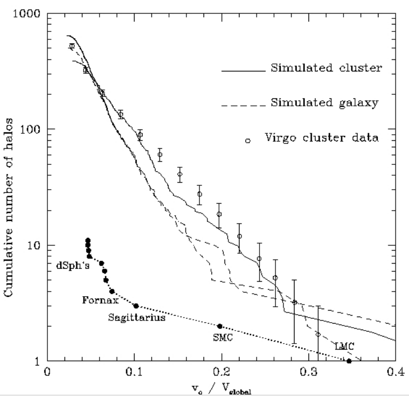
Spherical harmonic decomposition

Libeskind et al. (2010)

Preferential infall

Satellites tend to enter our galaxy from a preferred direction. The matter stripped from these subhalos retains a memory of that direction.

Missing satellites



The number of observed satellites is an order of magnitude smaller than the predicted number of subhalos.

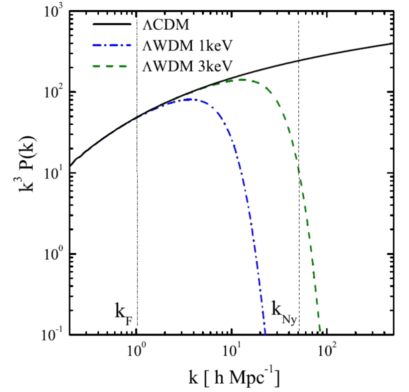
possible solutions:

- DM subhalos are more massive than assumed
- suppression of star formation
- no scale invariance of the power spectrum
  - Warm Dark Matter (small scale power erased)
  - a different inflationary model

Cosmology with Warm Dark Matter

LG formation in CDM and WDM scenarios

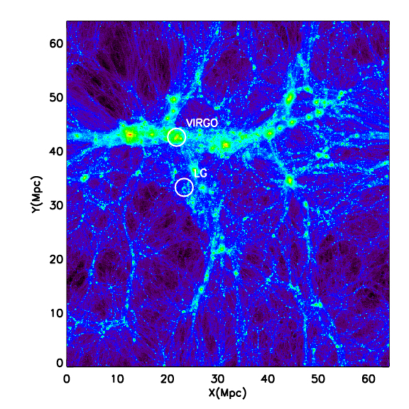
Cold vs. Warm Dark Matter



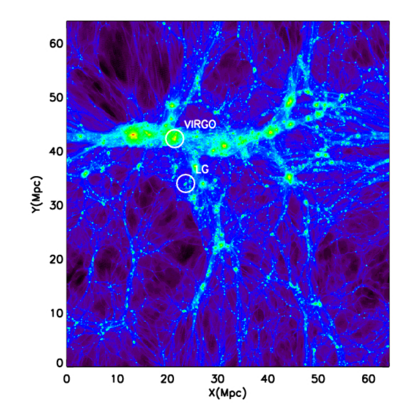
WMAP3

- $h = 0.73$
- $\Omega_m = 0.24$
- $\Omega_{bar} = 0.042$
- $\sigma_8 = 0.73$
- $n = 0.95$
- $m_{WDM} = 1$keV lower limit
- $k_{\rm peak} = 3.7h{\rm Mpc}^{-1}$

less small scale power $\Longrightarrow$ less small scale structure



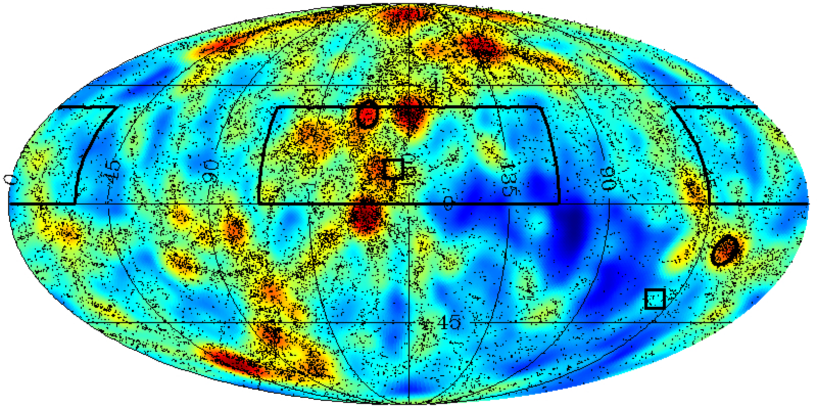
CDM



WDM

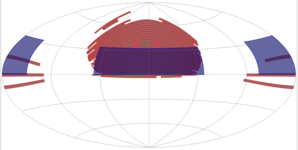
How does the nearby universe look like for an observer situated at the simulated MW?

Simulated sky map (Virgo/Fornax best fit)



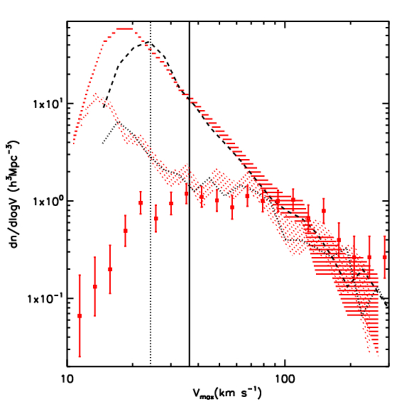
dots: halos with $M > 5 \times 10^9 h^{-1} \mathrm{M}_\odot$
squares: Virgo and Fornax, circles: their simulated counterparts

Arecibo Legacy Fast ALFA (ALFALFA) survey



- blind HI survey, started February 4, 2005 (6-7 years expected)
- detection of 20,000 galaxies expected within 200 Mpc
- gas rich galaxies with only a few or no stars ("dark")
- two arrays (Virgo and anti-Virgo)

ALFALFA observations in Virgo direction

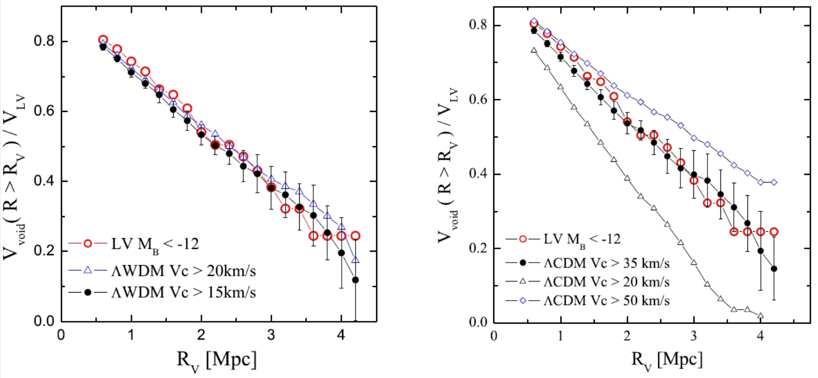


Zavala et al. (2009)

velocity function

- squares with error bars: galaxies taken from the ALFALFA catalogue with distances lower than $20h^{-1}\mathrm{Mpc}$
- predictions from the constrained simulation
  - ΛCDM: dashed red area
  - ΛWDM: dotted red area
  - dashed/dotted line: disk baryon fraction as function of halo mass (SN feedback)

Spectrum of mini-voids in the local volume $R < 8h^{-1}\mathrm{M}_\odot$



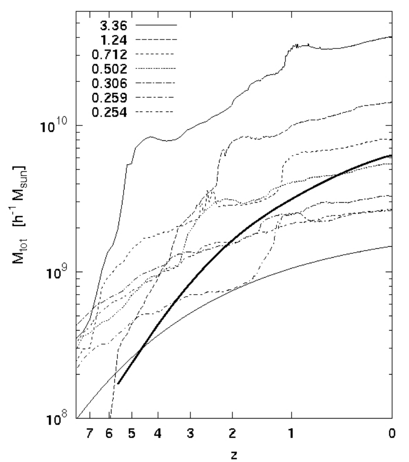
Warm Dark Matter

Cold Dark Matter

Tikhonov et al. (2009)

The observed spectrum of mini-voids could be easily explained with Warm Dark Matter halos, but do these halos contain galaxies?

Critical mass M_c of star formation



Hoeft et al. (2006)

- uniform UV-background (Haardt, Madau 1996)
- critical mass $M_c(z)$ for halos with low gas fraction (thick solid line)
- mass accretion history of seven halos (mass in $10^{10} h^{-1} \mathrm{M}_\odot$)
- mean mass accretion history of a $1.4 \times 10^9 h^{-1} \mathrm{M}_\odot$ halo

no star formation right of the thick solid line

The local small scale structure

The velocity function of nearby ALFALFA galaxies as well as the spectrum of mini-voids in the Local Volume point to a possible problem of the ΛCDM model on small scales.
Warm Dark Matter could be one solution to this long standing problem of overabundance of small scale structure (but there are also alternative explanations).

However, the nature of Dark Matter is still completely unknown (at least for astrophysicists).

Dark Matter (an artist's view)

Cornelia Parker
Cold Dark Matter: An Exploded View
1991, Mixed media
Presented by the Patrons of New Art
(Special Purchase Fund)
through the Tate Gallery Foundation
1995

http://www.tate.org.uk/modern/exhibitions/cinema/parker.htm

Dark Matter detection

- Direct detection
  - Look for elastic scattering of Dark Matter particles at nuclei
- Accelerator searches
  - Search for signs of "new physics"
- Indirect detection
  - Look for annihilation products
    - Photons
    - Neutrinos
    - Electron-Positron, ...

$\Longrightarrow$ astrophysics (CLUES - MULTIDARK)
http://projects.ift.uam.es/multidark

arXiv:1007.3469, yesterday

DARK MATTER DECAY AND ANNIHILATION IN THE LOCAL UNIVERSE: CLUES FROM *FERMI*

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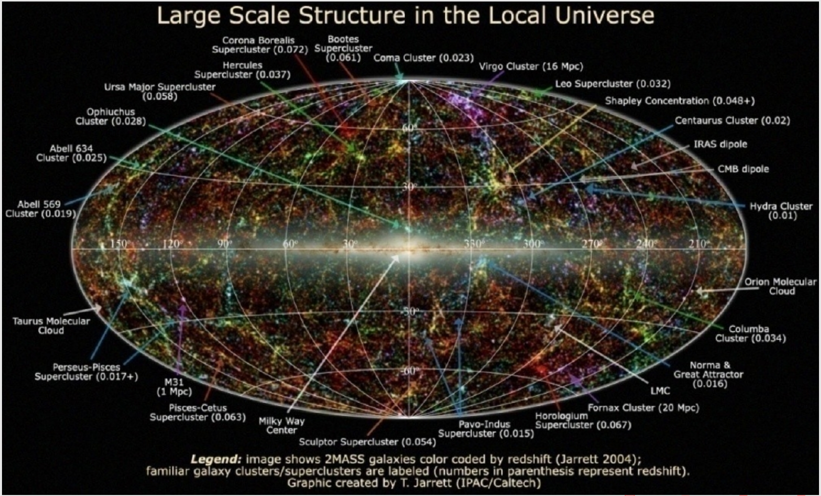
Draft version July 19, 2010

ABSTRACT

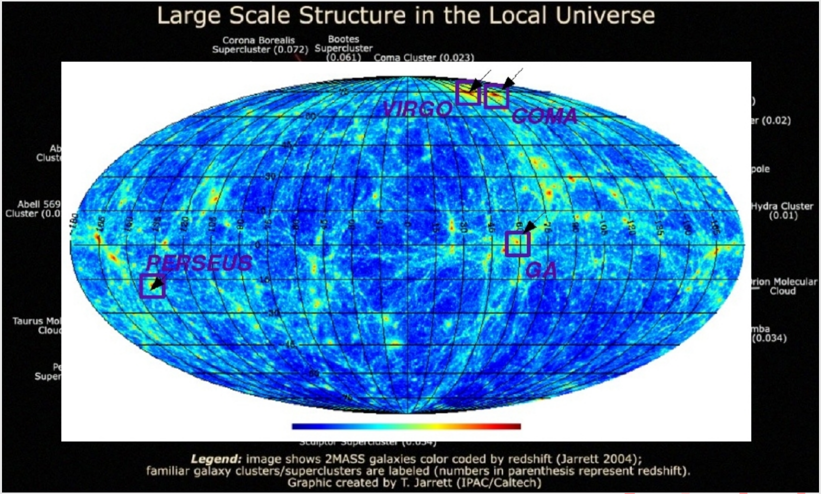
We present all-sky simulated *Fermi* maps of γ-rays from dark matter decay and annihilation in the Local Universe. The dark matter distribution is obtained from a constrained cosmological simulation of the neighboring large-scale structure provided by the CLUES project[1]. The dark matter fields of density and density squared are then taken as an input for the *Fermi* observation simulation tool to predict the γ-ray photon counts that *Fermi* would detect in 5 years of all-sky survey for given dark matter models. Signal-to-noise sky maps have also been obtained by adopting the current Galactic and isotropic diffuse background models released by the *Fermi* collaboration. We point out the possibility for *Fermi* to detect a dark matter γ-ray signal in extragalactic structures. In particular, we conclude here that *Fermi* observations of nearby clusters (e.g. Virgo and Coma) and filaments are expected to give stronger constraints on decaying dark matter compared to previous studies, especially for dark matter decay models fitting the positron excess as measured by PAMELA. This is the first time that dark matter filaments are shown to be promising targets for indirect detection of dark matter. We make the dark matter density and density squared maps available online at http://www.clues-project.org/articles/darkmattermaps.html.

Subject headings: astroparticle physics – dark matter – large-scale structure of Universe – gamma-rays: diffuse background – methods: numerical

The local Universe



The local CLUES universe

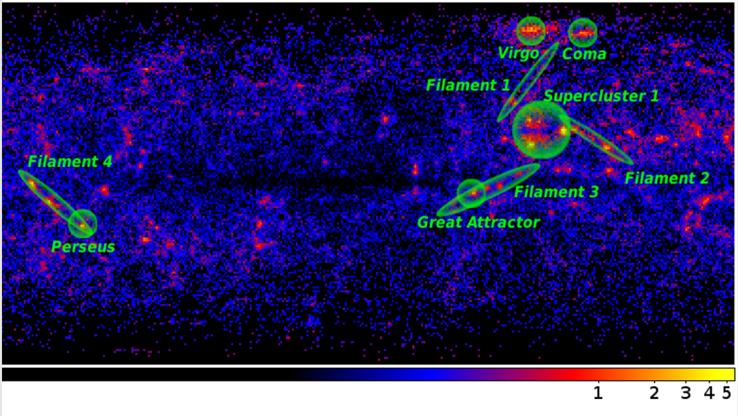


Antonio Cuesta

Fermi observation simulation

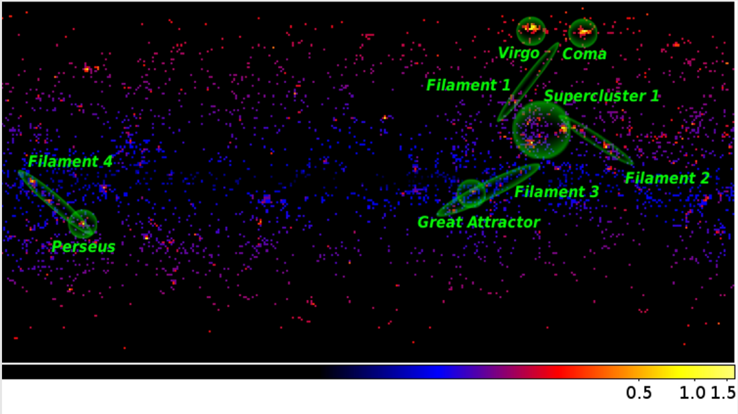
- Simulated Fermi maps take the DM distribution as an input and return the gamma-ray flux.
- The routine used here is gtobssim in Fermi Science Tools package (v9r15p2)
- Generated maps assume a 5-year observation in the default scanning mode using current release of LAT response functions (P6_V3_DIFFUSE)
- Isotropic diffuse backgrounds use the current models released by the Fermi Collaboration (gll_iem_v02.fit and isotropic_iem_v02.txt)

Dark Matter decay



S/N all-sky maps from *Fermi* simulations of γ-rays in the energy range 100 MeV–10 GeV resulting from Dark Matter particles decay in the Local Universe (assuming the $b\bar{b}$ channel model).

Dark Matter annihilation



S/N all-sky maps from *Fermi* simulations of γ-rays in the energy range 100 MeV–10 GeV resulting from Dark Matter particles annihilation in the Local Universe (assuming the $b\bar{b}$ channel model).

Indirect Dark Matter detection with Fermi

For a given DM model we predict γ-ray photon counts that *Fermi* would detect in 5 years of an all-sky survey and conclude that observations of clusters with high galactic latitude and nearby filaments are expected to provide constraints on decaying dark matter.

The end

Constrained simulations are a useful tool to study the local universe.

Thank you!

Antonio's plot

DM models

- 100 GeV neutralino
- $b\bar{b}$ channel
- γ-rays from π^0 (no IC)
- SUSY bino-like LSP
- $\langle\sigma v\rangle$=1e-23 $cm^3 s^{-1}$
- τ=1e26 s

- 1.6 TeV particle
- $\mu^+\mu^-$ channel
- γ-rays from FSR + IC
- fits PAMELA data
- $\langle\sigma v\rangle$=5.8e-23 $cm^3 s^{-1}$
- τ=3e26 s