Near Field Cosmology

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Cordoba
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From Large Volumes to Near Field Cosmology

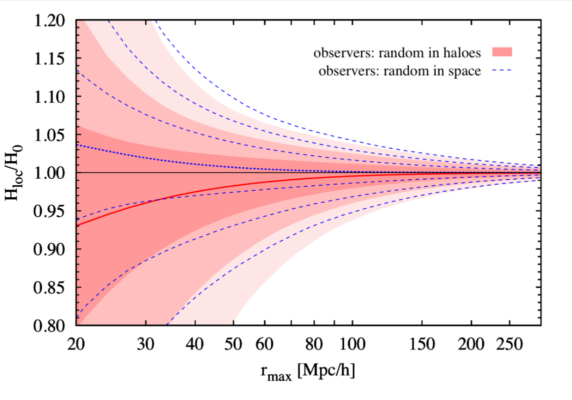
JUBiLEE: JUropa huBbLE volumE

An N-body simulation with 216 billion particles

in a volume of $(6000h^{-1}\mathrm{Mpc})^3$

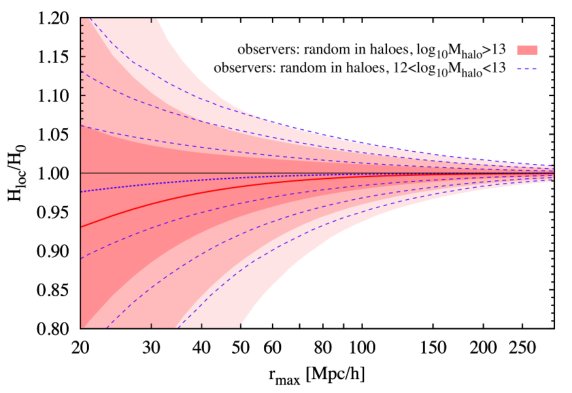
http://jubilee.ft.uam.es/

Probability distribution of the local Hubble parameter



Wojtak etal, MNRAS 438 (2014), 1805

Probability distribution of the local Hubble parameter



Wojtak etal, MNRAS 438 (2014), 1805

The MultiDark project

A series of DM only simulations

from $64h^{-1}\mathrm{Mpc}$ to $4000h^{-1}\mathrm{Mpc}$ boxes

with 3840^3 or 4096^3 particles

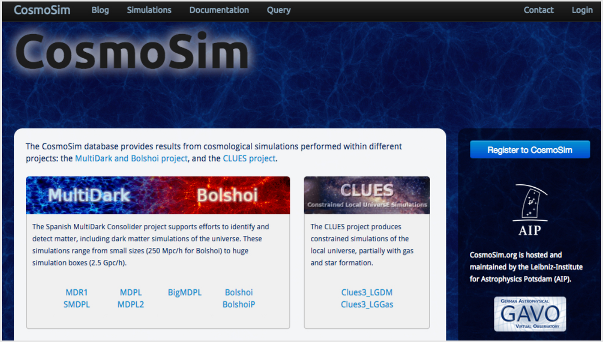
assuming Planck cosmology

Table of MulitiDark simulations

Simulation	box [h^{-1} Mpc]	particles	m_p [$h^{-1} M_\odot$]	ϵ [h^{-1} kpc]
HMD	4000	4096^3	8.0×10^{10}	50.0
BigMD	2500	3840^3	2.4×10^{10}	10.0
MD	1000	3840^3	1.5×10^{9}	5
SMD	400	3840^3	9.6×10^{7}	1.5
VSMD	160	3840^3	6.2×10^{6}	0.5
ESMD	64	4096^3	3.2×10^{5}	

The CosmoSim database at AIP

CosmoSim database



http://www.cosmosim.org/

Kristin Riebe, Adrian Partl, Jochen Klar, Harry Enke

Project supported by MultiDark and the German Astrophysical Virtual Observatory (GAVO)

Simulations performed at LRZ Munich, BSC Barcelona, JSC Juelich, NAS Ames

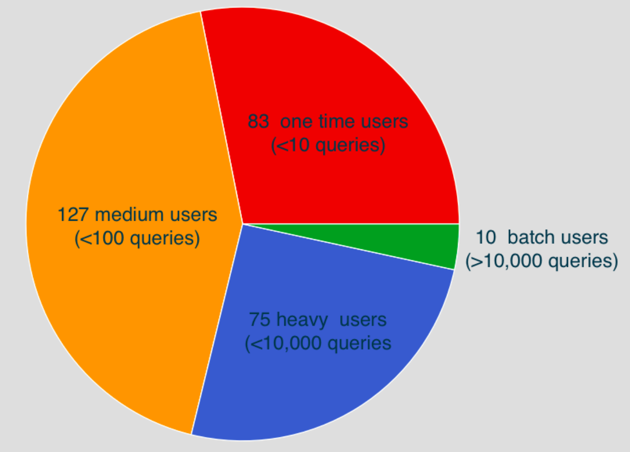
DB contains catalogs of objects as well as raw data

- FOF
  - catalogs at 4 different linking lengths (different overdensities)
  - FOF objects and subhalos
  - supercluster (and clusters within them)
  - merging tree
- spherical overdensity halos (BDM, Rockstar)
  - catalogs (halos and sub-halos)
  - profiles, shapes, spins, etc.
  - merging trees
- galaxies (SAM) coming soon
  - GALACTICUS
  - SAG
  - SAGE

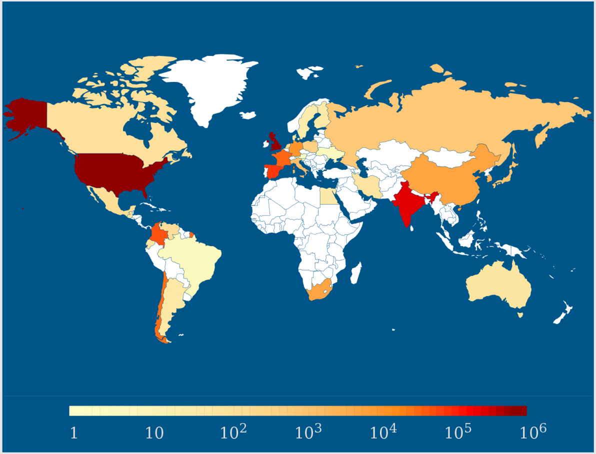
Database Spring 2017

- 45 Tb data + 19 Tb index
- 378 billion rows
- 295 active users (485 registrations)
- about 2.27 million successful queries
- currently 720 Gb in user tables

Database user statistics



Database user statistics



Number of queries per country (Spring 2017)

Near Field Cosmology

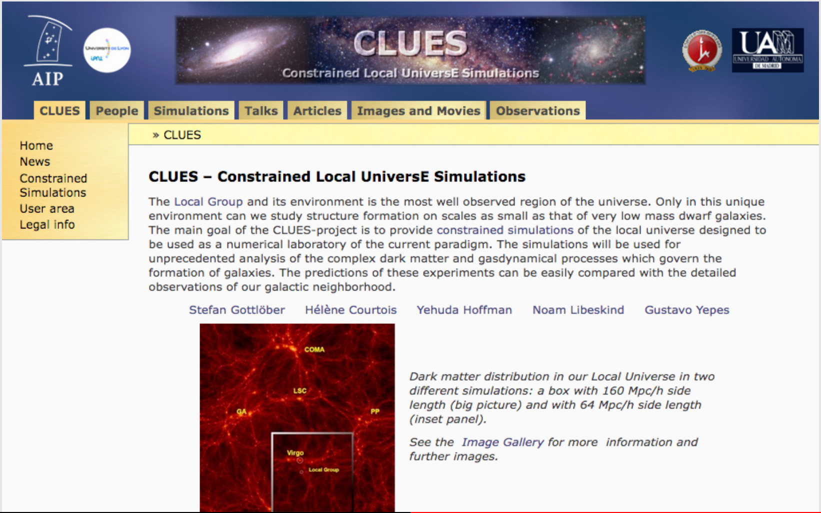
Why are we interested in the Local Universe?

- 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, for example number of dwarfs in the local volume.
- However, the local universe is not a representative part of the universe. It is dominated by the Local Group with two massive galaxies, the huge Local Void and a few clusters which build together the Laniakea Supercluster (Brent Tully, lani = sky, heaven, akea = broad, wide).
- Constrained simulations are an ideal tool to compare theoretical predictions (computer experiments) with local observations

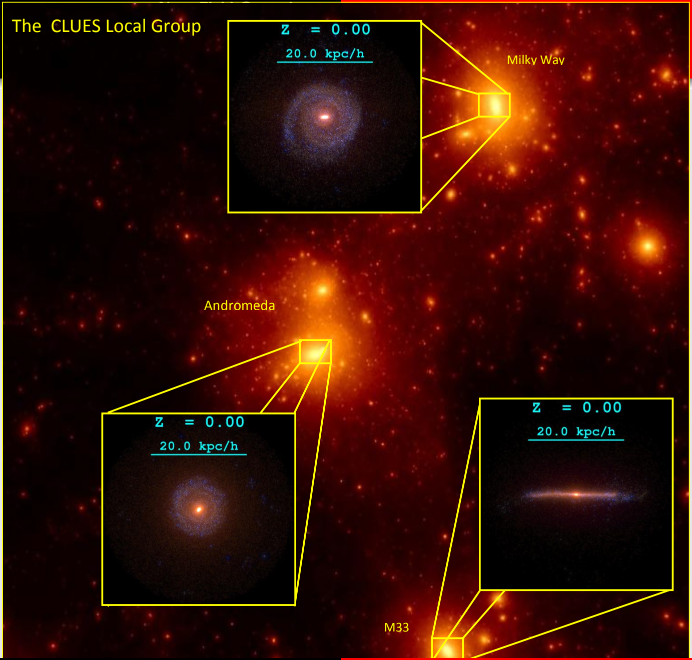
A short (and incomplete) history of constrained simulations

- Kolatt T. et al. APJ 458 (1996), 419, "Simulating our Cosmological neighborhood: Mock catalogs for velocity analysis"
- Bistolas V., Hoffman Y., APJ 492 (1998), 439 "Nonlinear constrained realisations of the large scale structure"
- Klypin A. et al, APJ 596 (2003), 19, "Constrained Simulations of the Real Universe: the Local Supercluster"
- Lavaux G., MNRAS 406 (2010), 1007 "Precision constrained simulation of the local universe"
- Heß S. et al., MNRAS 435 (2013), 2065 "Simulating Structure Formation of the Local Universe"
- Wang H. et al., APJ 794 (2014), "ELUCID - Exploring the Local Universe with reConstructed Initial Density field I: Hamiltonian

CLUES


AIP
CLUES
Constrained Local UniversE Simulations
UAM
UNIVERSIDAD AUTONOMA DE MADRID
CLUES
People
Simulations
Talks
Articles
Images and Movies
Observations
Home
News
Constrained Simulations
User area
Legal info
» CLUES
CLUES – Constrained Local UniversE Simulations
The Local Group and its environment is the most well observed region of the universe. Only in this unique environment can we study structure formation on scales as small as that of very low mass dwarf galaxies. The main goal of the CLUES-project is to provide constrained simulations of the local universe designed to be used as a numerical laboratory of the current paradigm. The simulations will be used for unprecedented analysis of the complex dark matter and gasdynamical processes which govern the formation of galaxies. The predictions of these experiments can be easily compared with the detailed observations of our galactic neighborhood.
Stefan Gottlöber
Hélène Courtois
Yehuda Hoffman
Noam Libeskind
Gustavo Yepes
COMA
LSC
GA
PP
Virgo
Local Group
Dark matter distribution in our Local Universe in two different simulations: a box with 160 Mpc/h side length (big picture) and with 64 Mpc/h side length (inset panel).
See the Image Gallery for more information and further images.

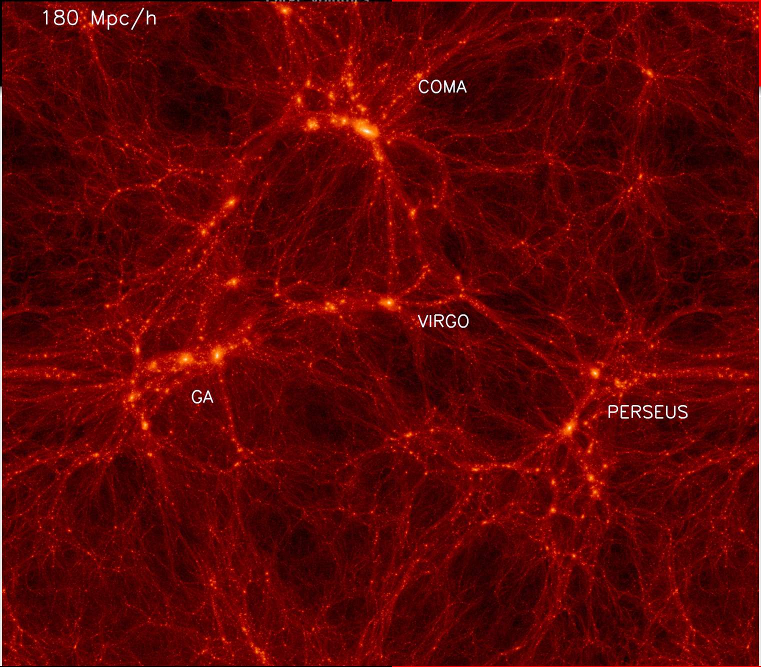
CLUES topics (from 63 titles of papers)

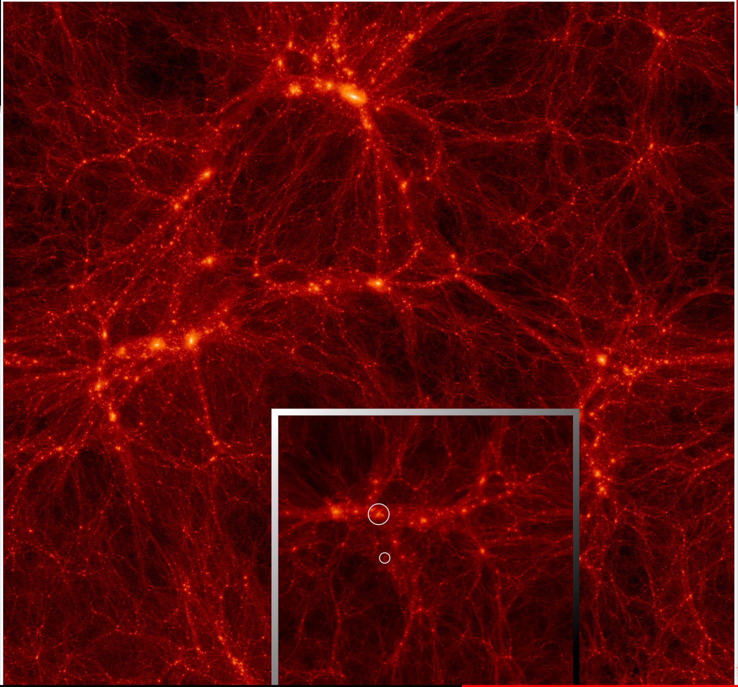

The CLUES Local Group
Z = 0.00
20.0 kpc/h
Milky Way
Andromeda
Z = 0.00
20.0 kpc/h
Z = 0.00
20.0 kpc/h
M33

Observational data and constraints for CLUES

- Wiener Filter (Zaroubi et al., 1995)
- Hoffman-Ribak algorithm (Hoffman & Ribak, 1991)
- Radial velocity field (MARK III, Willick et al., 1997, Tonry 2001, Karachentsev 2004)
- Nearby cluster positions (Reiprich & Böhringer, 2002)

- CosmicFlows-2 (Tully et al. 2013)
- Reverse Zeldovich Approximation (Doumler et al. 2012, Sorce et al 2014)
- Grouping of velocity data (Tully 2014, Sorce,Tempel 2017)
- Malmquist bias correction (Sorce 2015)
- CosmicFlows-3 (Tully, Courtois, Sorce 2016)


180 Mpc/h
COMA
VIRGO
GA
PERSEUS

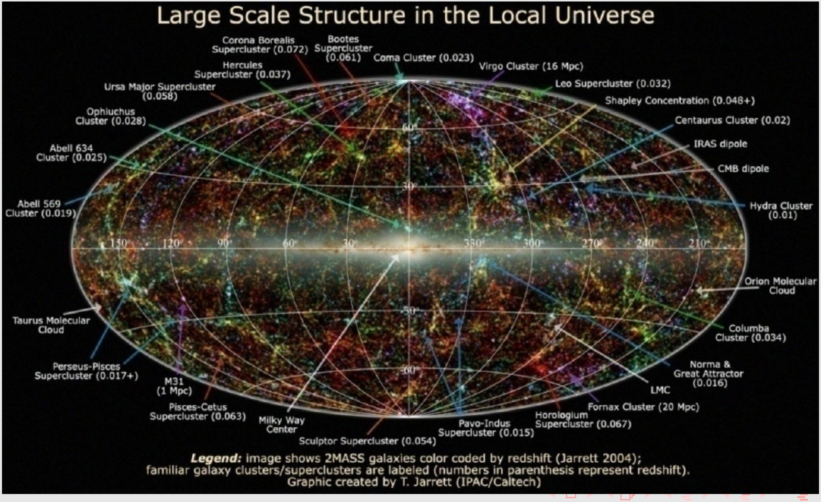


$160h^{-1}\mathrm{Mpc}$
Anatoly Klypin

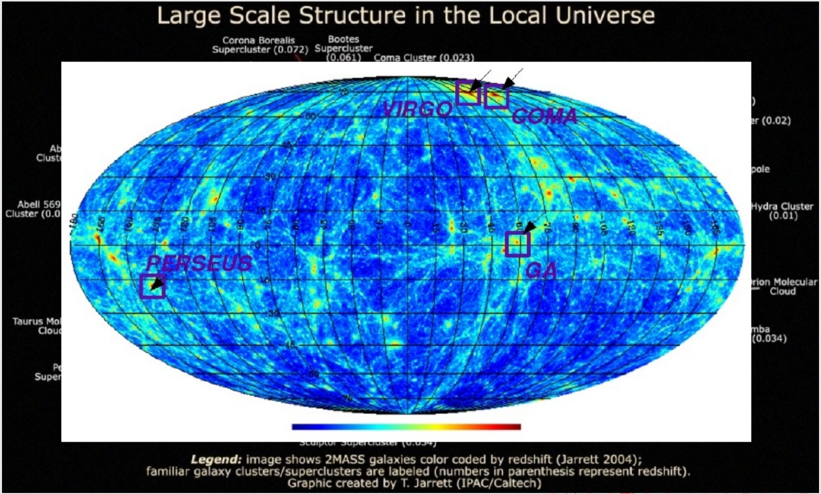
$64h^{-1}\mathrm{Mpc}$
Gustavo Yepes

The Local Volume simulations

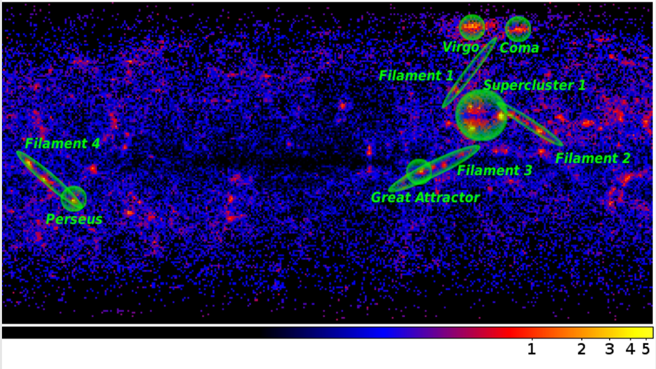
The Local Volume



The Local Volume



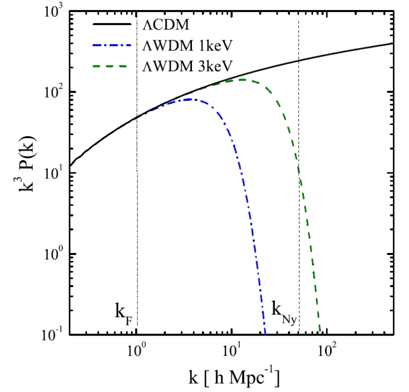
Fermi Simulation



Gamma-ray photon counts (100 MeV - 10 GeV) which Fermi would detect in 5 years of an all sky survey

Cuesta et al. ApJ 2011

Cold vs. Warm Dark Matter

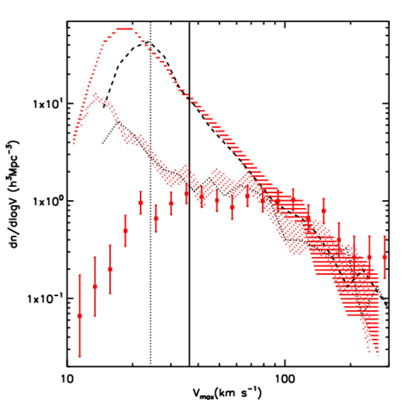


WMAP3

- $h = 0.73$
- $\Omega_m = 0.24$
- $\Omega_{bar} = 0.042$
- $\sigma_8 = 0.75$
- $n = 0.95$
- $m_{WDM} = 1\text{keV}$ lower limit
- $k_{\text{peak}} = 3.7h\text{Mpc}^{-1}$

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

ALFALFA observations in Virgo direction



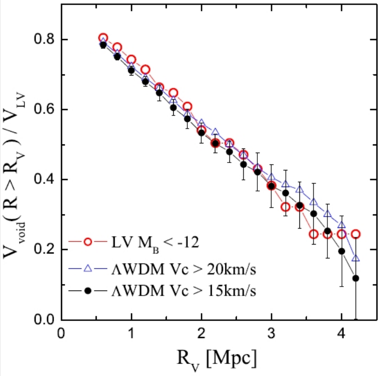
Zavala et al. (2009)

velocity function

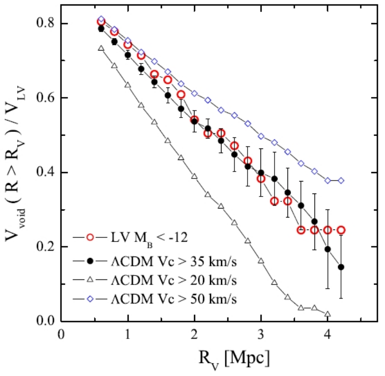
- squares with error bars: galaxies taken from the ALFALFA catalog with distances lower than $20h^{-1}\mathrm{Mpc}$
- predictions from the constrained simulation
  - ΛCDM: dashed red area
  - ΛWDM: dotted red area
  - dashed/dotted line: disk baryon fraction as function of halo mass (SN feedback)

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

Warm Dark Matter



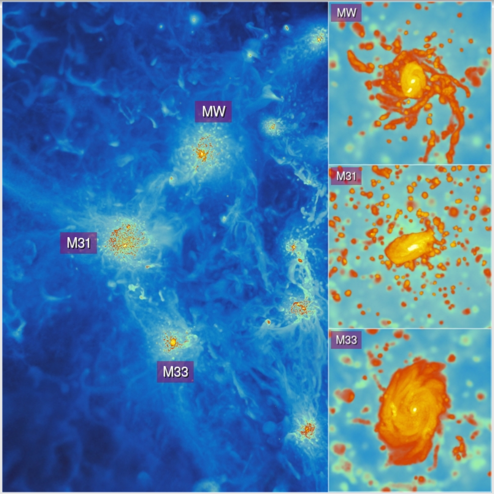
Cold Dark Matter



Tikhonov and Klypin (2009), Tikhonov et al. (2009)

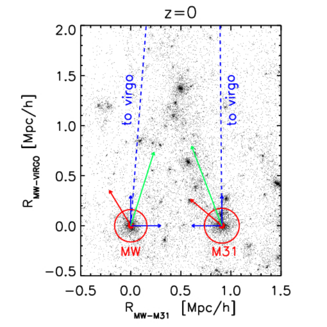
The Local Group simulations

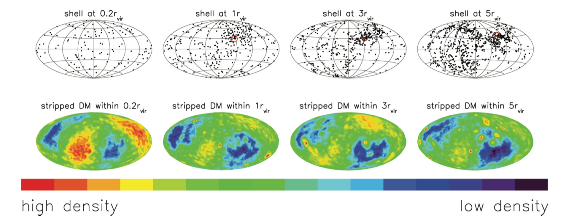
Gas distribution in the local group



- box $64h^{-1}\mathrm{Mpc}$
- 4096^3 particles locally
- DM particles: $2.1 \times 10^5 h^{-1}\mathrm{M}_\odot$
- gas particles: $4.4 \times 10^4 h^{-1}\mathrm{M}_\odot$
- force resolution: $0.15h^{-1}\mathrm{kpc}$

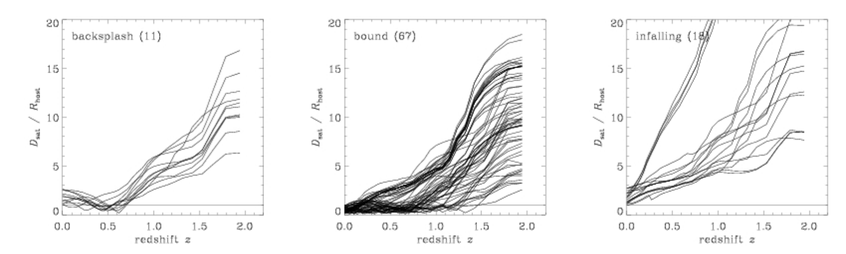
Preferential infall





Libeskind et al. (2011)

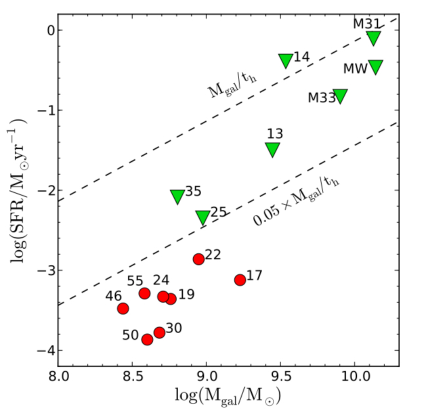
Backsplash galaxies



a substantial fraction of halos outside of the virial radius of the massive host halos have been inside the virial radius before, and there are renegades too

Knebe et al. 2011

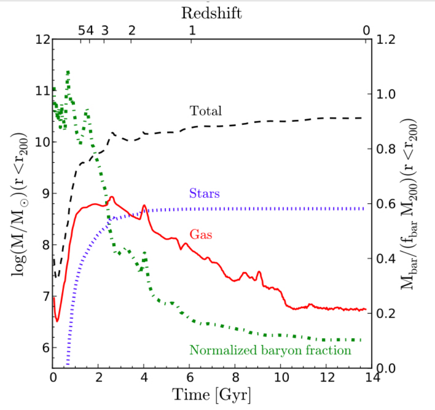
Dwarfs in the Local Group



Alejandro Benitez-Llambay et al. (2013)

- isolated dwarfs without interactions with one of the massive galaxies in the past
- all within a sphere of R = 1.5 Mpc/h of the center of the Local Group
- triangles: galaxies that form stars at rates comparable to their past average
- circles: star formation has largely ceased

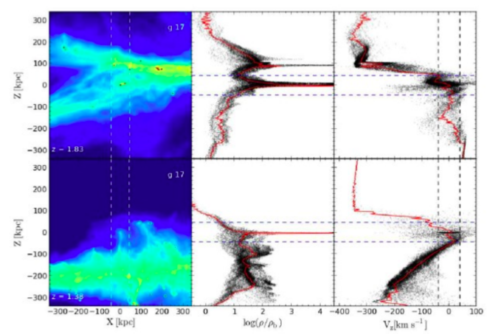
Dwarfs in the Local Group



Alejandro Benitez-Llambay et al. (2013)

- masses within the virial radius of galaxy 30
- sudden loss of baryons at $z \approx 2$
- ram pressure arising from crossing a large-scale pancake

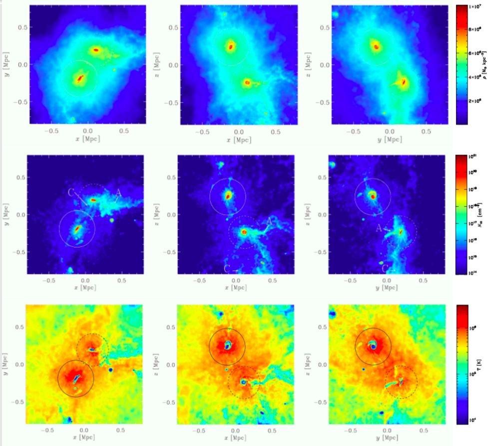
Cosmic web stripping



Alejandro Benitez-Llambay et al. (2013), movies made by Alejandro

- gas from the halo is removed by the cosmic web environment due to ram pressure
- **Cosmic Web Stripping**

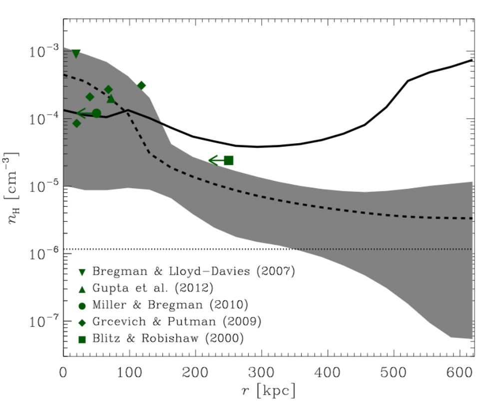
Gas distribution around MW and M31



Sebastian Nuza et al. (2014)

- gas density (upper panel)
- HI column density (middle panel)
- temperature (lower panel)
- virial radius (circles)

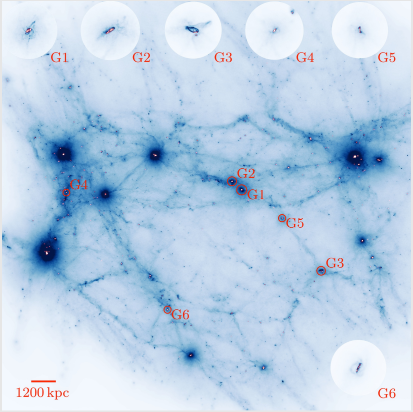
Gas distribution around MW and M31



Sebastian Nuza et al. (2014)

- hydrogen number density profile
- shaded area:standard deviation over random directions
- thick line: direction to Andromeda

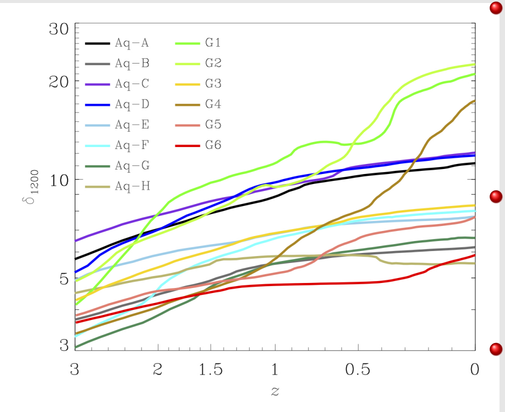
Milky Way and Andromeda



Peter Creasey et al. (2015)

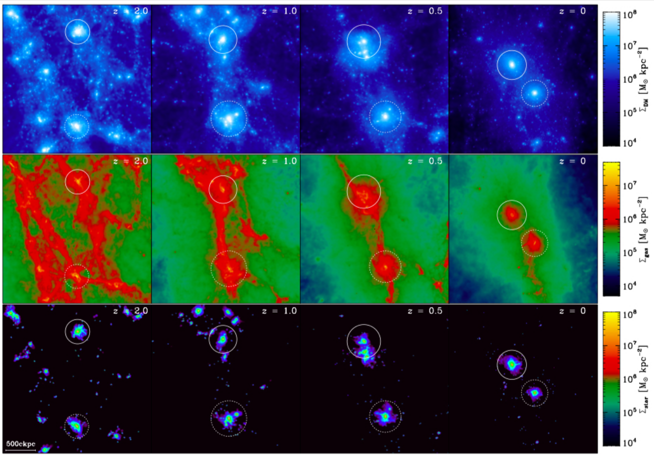
- column density of gas (blue) overlaid with star forming gas (orange-white)
- simulation performed with the Scannapieco version of Gadget
- comparison to Aquarius galaxies

Milky Way and Andromeda



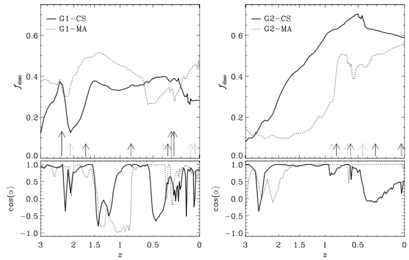
Peter Creasey et al. (2015)

- Environmental overdensity δ_{1200} (within 1200 kpc) vs. redshift for the galaxies in the LG and Aquarius samples
- similar environments at $z \sim$ 2-3, G1, G2 and G4 exhibit stronger evolution after $z \approx 2$
- inhabit gaseous filaments (previous plots)



Cecilia Scannapieco et al. (2015)

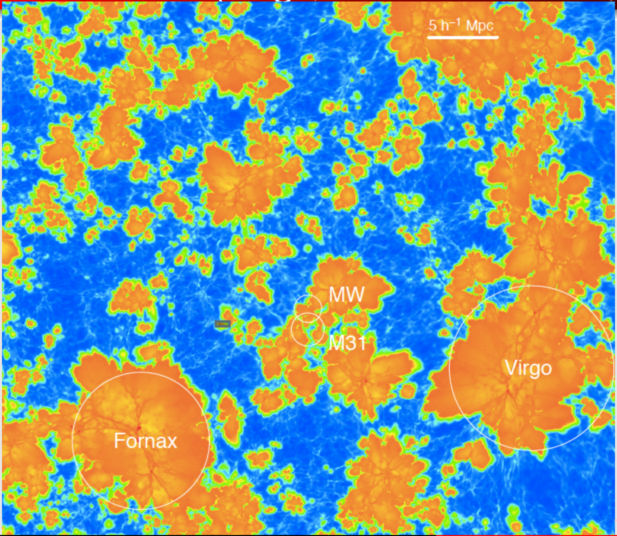
Milky Way and Andromeda



Cecilia Scannapieco et al. (2015)

- evolution of the disc-to-total measure $f_{\rm disc}$
- evolution of the angle between the angular momentum vectors of the gas and stars
- long/short arrows denote the entrance of major/intermediate mass mergers in the inner 30 kpc

Cosmic Dawn (Virgo, Fornax vs. Cen A, M81)



4096^3 particles in $64h^{-1}$Mpc box

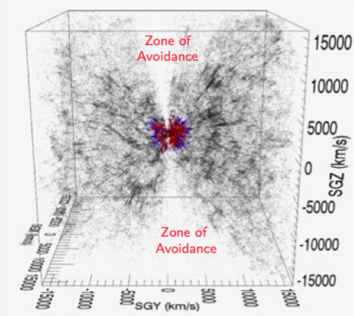
Temperature distribution at z= 6.15

orange: photo-heated,ionized
blue: cold, neutral

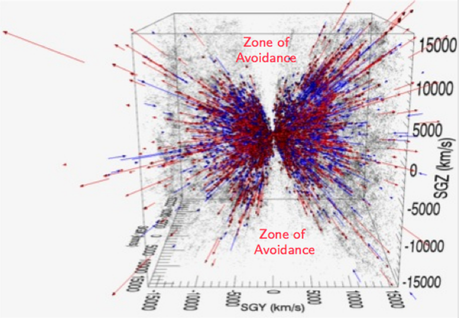
Pierre Ocvirk et al. (2016)

CLUES with CosmicFlows

CosmicFlows-2



Cosmicflows-1
about 2000 constraints
Tully et al. 2008

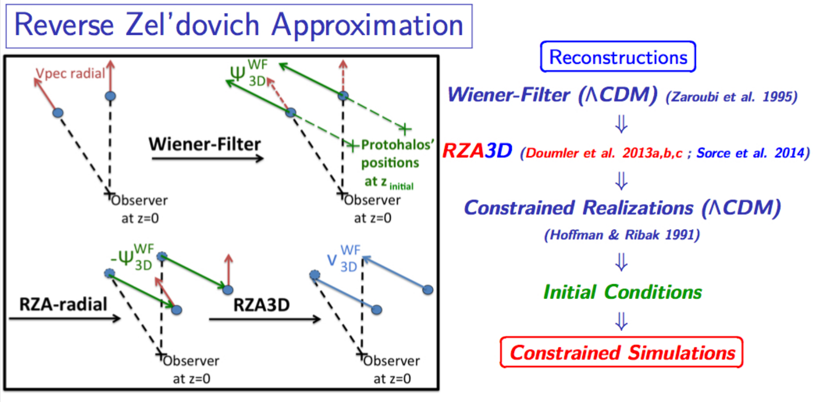


Cosmicflows-2
about 8000 constraints
Tully et al. 2013

Simulations based on CosmicFlows2 data

and the Reverse Zeldovich Approximations (RZA)

RZA



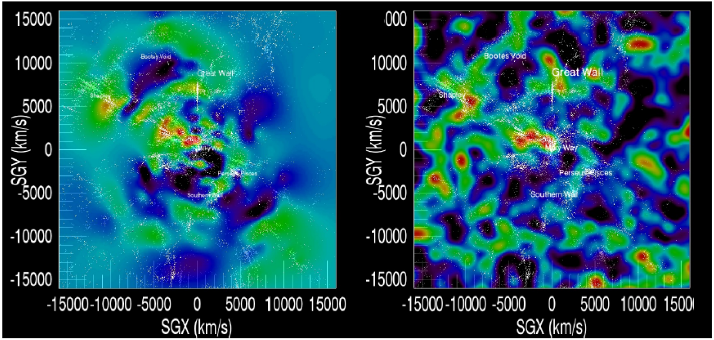
Jenny Sorce (2014)

Const

The Large Scale Structure

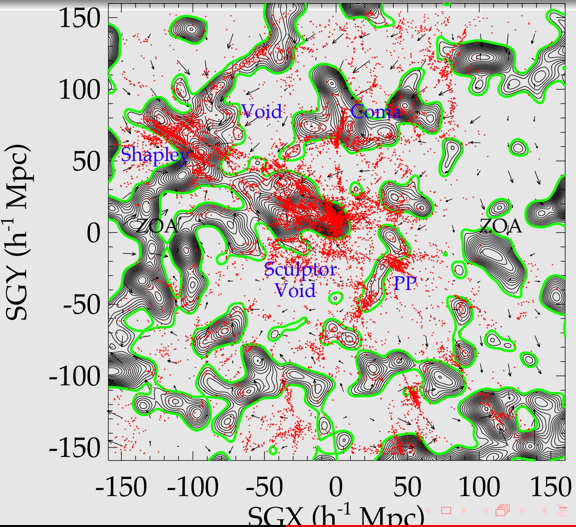
At $z = 0$,

Reconstruction | Simulation

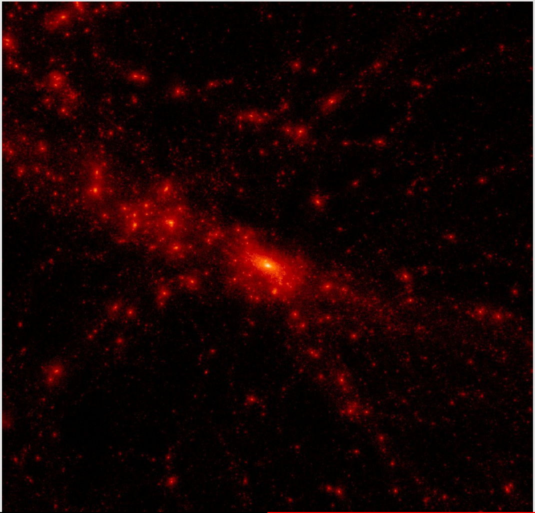


Periodic Boundary Conditions, L=500 h^{-1} Mpc , $n^3=512^3$

Constrained simulations of the Local Universe

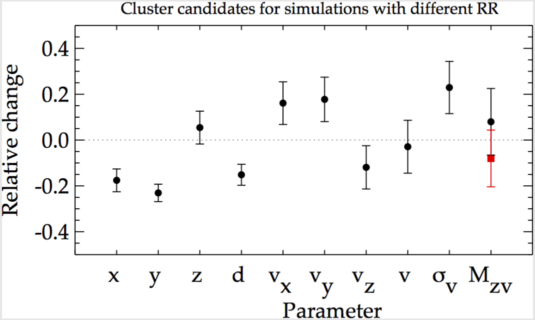


Virgo



Virgo properties

Dist	sgl	sgb	sgx	sgy	sgz	v [km/s]	$M_{ZV} [10^{14} M_\odot]$	σ_v
11.1	103.2	-2.612	-2.56	10.9	-0.512	645	3.9 ± 2.1 [a] - 5.4 ± 1.6 [b]	665



Virgo properties

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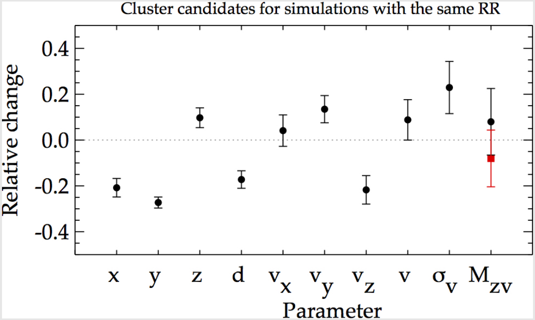
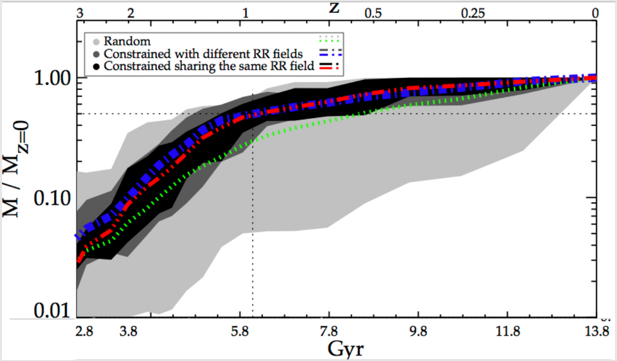


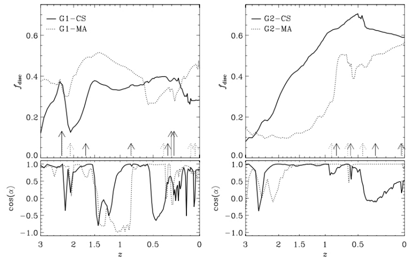
Virgo merging history



Jenny Sorce et al (2016)

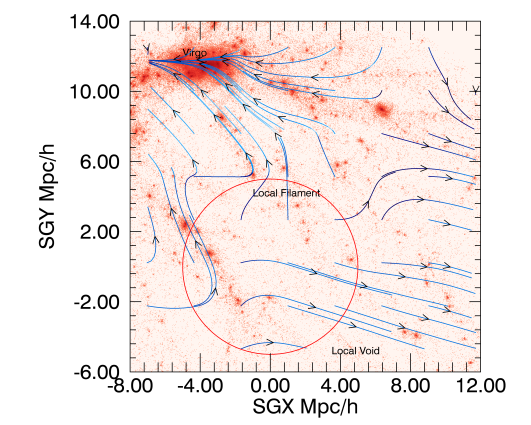
The Local Group factory

- Why do we need a local group factory?



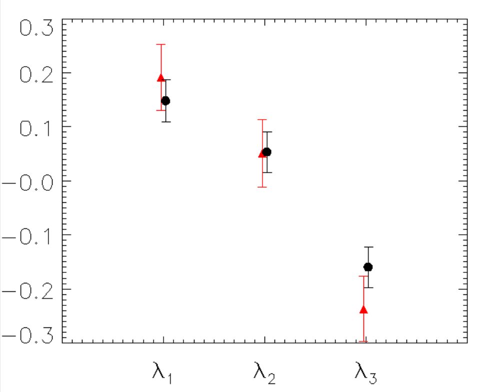
- correct relative masses
- quite merging history
- ....

The Local Group factory



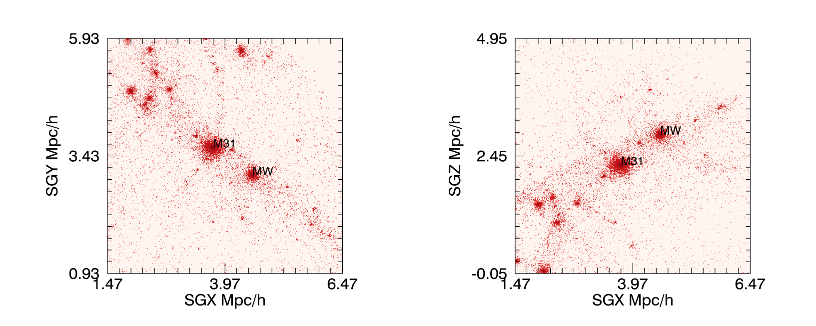
Edoardo Carlesi et al (2016)

The Local Group factory



- Velocity shear tensor eigenvalues and their standard deviations at the centre of the box (red), observed values (black, Libeskind et al 2015)

The Local Group factory



Edoardo Carlesi et al (2016)

Thanks to my collaborators

Summary

- Constrained numerical simulations are an important tool to study the formation of the observed structures in the local universe. In particular locally observed dwarfs are a target of such simulations.
- The CF2 data together with the improved reconstruction technique substantially improve the quality of our constrained simulations
- An increasing number of both constrained and unconstrained simulations are available at the CosmoSim database of AIP.