The near field (cosmology) from a Bayesian perspective

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Ofer@60 (April 9, 2019)

Work with Ofer in the early 90s

#	Bibcode / Authors	Score / Title	Date	List of Links / Access Control Help
1	1995ApJ...449..446Z Zaroubi, S.; Hoffman, Y.; Fisher, K. B.; Lahav, O.	1.000 Wiener Reconstruction of the Large-Scale Structure	08/1995	A F G X R C
2	1995MNRAS.272..885F Fisher, K. B.; Lahav, O.; Hoffman, Y.; Lynden-Bell, D.; Zaroubi, S.	1.000 Wiener reconstruction of density, velocity and potential fields from all-sky galaxy	02/1995	A E F G X R C
3	1994ApJ...432L..75B Bunn, Emory F.; Fisher, Karl B.; Hoffman, Yehuda; Lahav, Ofer; Silk, Joseph; Zaroubi, Saleem	1.000 Wiener filtering of the COBE Differential Microwave Radiometer data	09/1994	A F G X R C
4	1994ApJ...423L..93L Lahav, O.; Fisher, K. B.; Hoffman, Y.; Scharf, C. A.; Zaroubi, S.	1.000 Wiener Reconstruction of All-Sky Galaxy Surveys in Spherical Harmonics	03/1994	A F G X R C S
5	1992MNRAS.256..229S Scharf, Caleb; Hoffman, Yehuda; Lahav, Ofer; Lynden-Bell, Donald	1.000 Spherical harmonic analysis of IRAS galaxies - Implications for the Great Attract	05/1992	A E F G R C S
6	1991NYASA.647..687H Hoffman, Y.; Scharf, C.; Lahav, O.	1.000 The angular large-scale structure.	00/1991	A E T R
7	1990ApJ...352..448L Lahav, Ofer; Kaiser, Nick; Hoffman, Yehuda	1.000 Local gravity and peculiar velocity - Probes of cosmological models	04/1990	A F G R C

WF/CRs applied to the CMB (COBE 1st year data)

WIENER FILTERING OF THE *COBE* DIFFERENTIAL MICROWAVE RADIOMETER DATA

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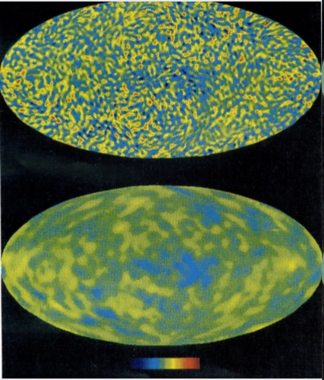
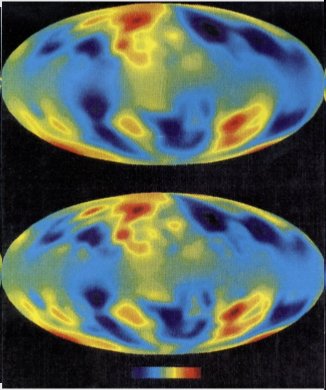
JOSEPH SILK,[1] AND SALEEM ZAROUBI[4]

Received 1994 April 11; accepted 1994 June 23

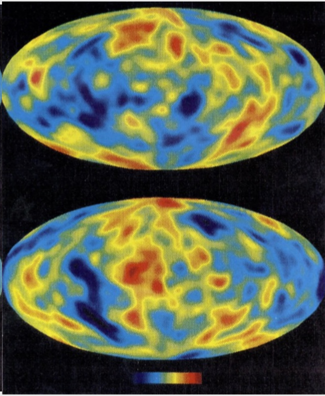
COBE (raw data)



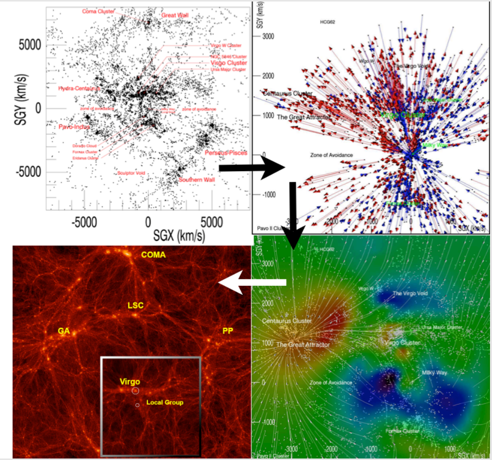
COBE (WF)



COBE (CRs)



CLUES (in a nutshell)



Key ingredients

- Data: peculiar velocities of galaxies
- Prior model: ΛCDM
- Bayesian construction of the (linear) large scale structure (LSS) from noisy, sparse and incomplete data
- Time machine: from the (present epoch) reconstructed LSS to initial conditions (ICs)
- Constrained simulations: from ICs to the present epoch nearby universe
- Construct an ensemble of constrained simulations
- The mean (or median) over the ensemble of constrained simulation = estimator of the QL nearby universe

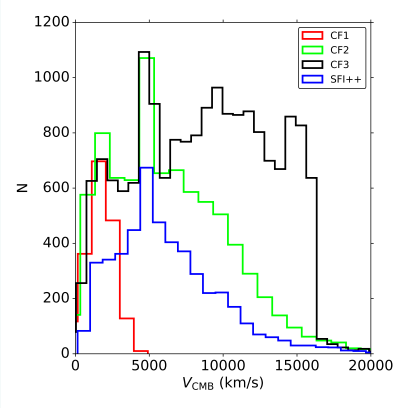
Bayesian inference: WF/CRs/Constrained simulations

In the Bayesian approach one is interested in the posterior probability of a model given observational data:

$$P(\text{model} \mid \text{data}) \propto P(\text{data} \mid \text{model})\ P(\text{model})$$

- P(model) is the prior probability (knowledge) of the model
- P(data | model) is the likelihood of the data given the (prior) model: how likely is a data given the model
- P(model | data) is the posterior probability: **how likely is a model given the data and one's prior knowledge**. The model is a mathematical abstraction that describes a physical system (e.g. density or velocity field).

- Model: Gaussian random field, with the ΛCDM power spectrum
- Data: peculiar velocities of galaxies (Cosmicflows database)
- Sampling the posterior probability (linear regime): by constrained realizations (CRs) of Gaussian fields
- Posterior probability distribution function (linear regime): mean and most probable field are given by the Wiener filter (WF)
- Sampling the posterior probability (non-linear regime): by constrained simulations



Cosmicflows project: database of galaxies with estimated distances:

Cosmicflows-1 (CF1): 1797 galaxies within 3000 $\mathrm{km\ s^{-1}}$ (575 grouped data)

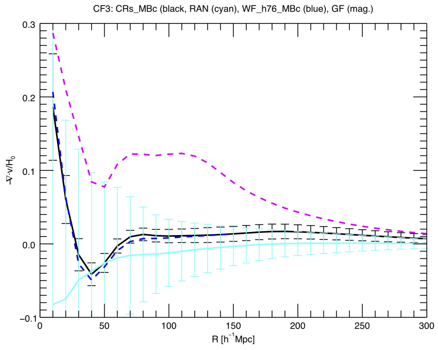
Cosmicflows-2 (CF2): ≈8000 galaxies with median redshift of 5895 $\mathrm{km\ s^{-1}}$ (4814 grouped)

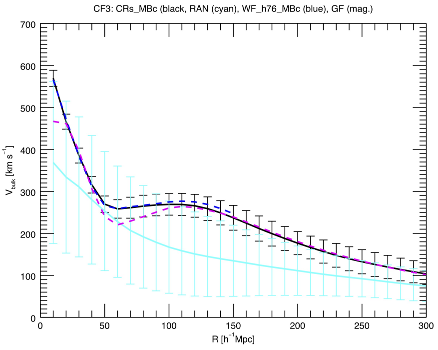
Cosmicflows-3 (CF3): ≈18000 galaxies with median redshift of ≈8000 $\mathrm{km\ s^{-1}}$ (≈ 11000 grouped)

Cosmicflows-4 (CF4): in progress

CF3 data and Planck ΛCDM model

Comparison of the monopole ($-\nabla \cdot \vec{v}/H_0$) and dipole (bulk velocity) moments (in top-hat spheres of radius R) of constrained realizations with random ones.





Institute for Astronomy
University of Hawaii

Hawaii Scientist Maps, Names Laniakea, Our Home Supercluster of Galaxies

Maintained by LG

For immediate release
September 3, 2014

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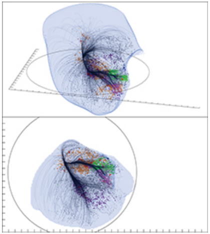
Illustrations:

University of Hawaii at Manoa astronomer R. Brent Tully, who recently shared the 2014 Gruber Cosmology Prize and the 2014 Victor Ambartsumian International Prize, has led an international team of astronomers in defining the contours of the immense supercluster of galaxies containing our own Milky Way. They have named the supercluster "Laniakea," meaning "immense heaven" in Hawaiian. The paper explaining this work is the cover story of the September 4 issue of the prestigious journal Nature.



Two views of the Laniakea Supercluster. The outer surface shows the region dominated by Laniakea's gravity. For more information, see caption for Figure 1 below. Credit: SDvision interactive visualization software by DP at CEA/Saclay, France.

Galaxies are not distributed randomly throughout the universe. Instead, they are found in groups, like our own Local Group, that contain dozens of galaxies, and in massive clusters containing hundreds of galaxies, all interconnected in a web of filaments in which galaxies are strung like pearls. Where these filaments intersect, we find huge structures, called "superclusters." These structures are interconnected, but they have poorly defined boundaries.

The researchers are proposing a new way to evaluate these large-scale structures by examining their impact on the motions of galaxies. A galaxy between two such structures will be caught in a gravitational tug-of-war in which the balance of the gravitational forces from the surrounding large-scale structures determines the galaxy's motion. By mapping the velocities of galaxies throughout our local universe, the team was able to define the region of space where each supercluster dominates.

The Milky Way resides in the outskirts of one such supercluster, whose extent has for the first time been carefully mapped using these new techniques. This Laniakea Supercluster is 500 million light-years in diameter and contains the mass of 10^{17} (a hundred quadrillion) suns in 100,000 galaxies.

This study clarifies the role of the Great Attractor, a problem that has kept astronomers busy for 30 years. Within the volume of the Laniakea Supercluster, motions are directed inwards, as water streams follow descending paths toward a valley. The Great Attractor region is a large flat bottom gravitational valley with a sphere of attraction that extends across the Laniakea Supercluster.

The name Laniakea was suggested by Nawa'a Napoleon, an associate professor of Hawaiian Language and chair of the Department of Languages, Linguistics, and Literature at Kapiolani Community College, a part of the University of Hawaii system.

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Newly Discovered Intergalactic Void Repels Milky Way

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0500HST 30 JANUARY 2017

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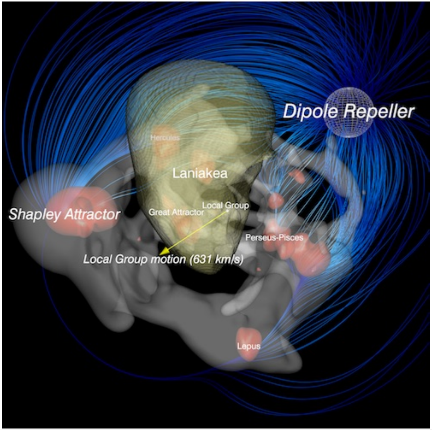
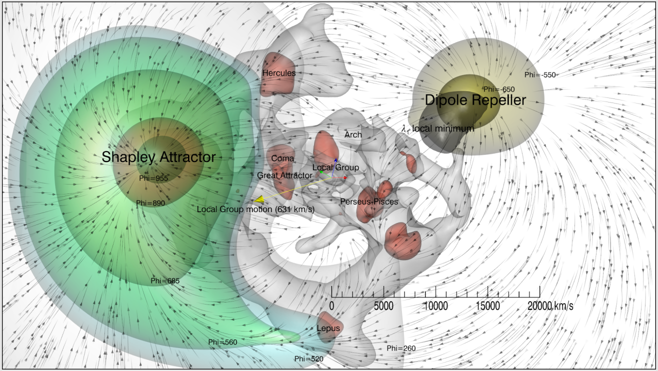
For decades, astronomers have known that our Milky Way galaxy - along with our companion galaxy, Andromeda - is moving through space at about 1.4 million miles per hour with respect to the expanding universe. Scientists generally assumed that dense regions of the universe, populated with an excess of galaxies, are pulling us in the same way that gravity made Newton's apple fall toward earth.

In a groundbreaking study published in Nature Astronomy, a team of researchers, including Brent Tully from the University of Hawaii Institute for Astronomy, reports the discovery of a previously unknown, nearly empty region in our extragalactic neighborhood. Largely devoid of galaxies, this void effectively exerts a repelling force, pushing our Local Group of galaxies through space.

Astronomers initially attributed the Milky Way's motion to the Great Attractor, a region of a half-dozen rich clusters of galaxies 150 million light-years away. Soon after, attention was drawn to a much larger structure called the Shapley Concentration, located 600 million light-years away, in the same direction as the Great Attractor. However, there has been ongoing debate about the relative importance of these two attractors and whether they suffice to explain our motion.





A face-on view of a slice $\pm 30h^{-1}\mathrm{Mpc}$ thick, normal to the direction of the pointing vector $\hat{r} = (0.604, 0.720, -0.342)$. Three different elements of the flow are presented: streamlines, red and grey surfaces present the knots and filaments of the V-web, and equipotential surfaces are shown in green and yellow. The yellow arrow indicates the direction of the CMB dipole.

The Dipole Repeller (DR) is located at: $[SGX, SGY, SGZ] \approx [110, -60, 100] \pm 25h^{-1}\mathrm{Mpc}$

Institute for Astronomy
University of Hawaii

The Cosmic Velocity Web

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FOR IMMEDIATE RELEASE
10 AUGUST 2017

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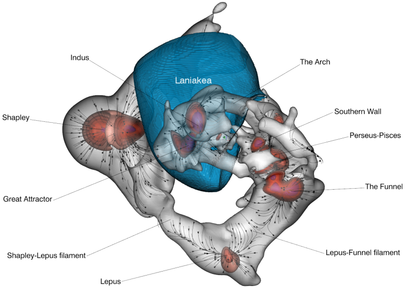
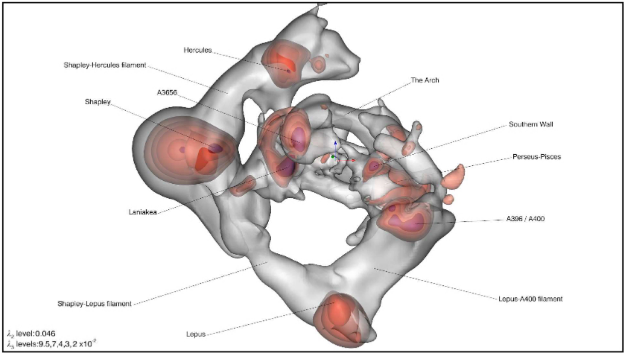
The cosmic web - the distribution of matter on the largest scales in the universe - has usually been defined through the distribution of galaxies. Now, a new study by a team of astronomers from France, Israel, and Hawaii demonstrates a novel approach. Instead of using galaxy positions, they mapped the motions of thousands of galaxies. Because galaxies are pulled toward gravitational attractors and move away from empty regions, these motions allowed the team to locate the denser matter in clusters and filaments and the absence of matter in regions called voids.

Matter was distributed almost homogeneously in the very early universe, with only miniscule variations in density. Over the 14 billion year history of the universe, gravity has been acting to pull matter together in some places and leave other places more and more empty. Today, the matter forms a network of knots and connecting filaments referred to as the cosmic web. Most of this matter is in a mysterious form, the so-called "dark matter". Galaxies have formed at the highest concentrations of matter and act as lighthouses illuminating the underlying cosmic structure.



The cosmic velocity web is represented by surfaces of knots in red and surfaces of filaments in grey. The black lines with arrows illustrate local velocity flows within filaments and toward knots. The Laniakea Supercluster basin of attraction that includes our Milky Way galaxy is represented by a blue surface. The region being displayed extends across one billion light years.
Credit: Daniel Pomarede, Yehuda Hoffman, R. Brent Tully, Helene Courtois.

The newly defined cosmic velocity web defines the structure of the universe from velocity information alone. In those regions with abundant observations, the structure of the velocity web and the web inferred from the locations of the galaxy lighthouses are



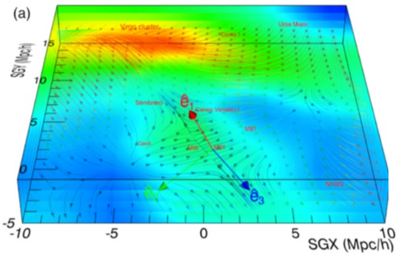
A 3D map of the Cosmic Web represented in terms of knots (red surfaces) and filaments (grey surface). Orientation and dimensions are provided by the three-arrows signpost located at the origin of the supergalactic coordinate system with its 2000 km/s long arrows pointing to the three cardinal directions (red, green, blue for SGX, SGY, SGZ, respectively).

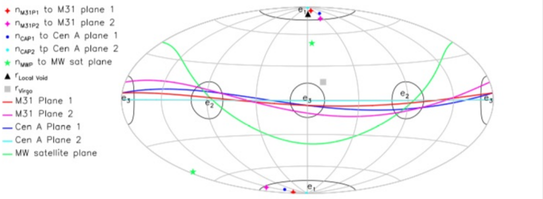
Planes of satellite galaxies and the cosmic (V-)web

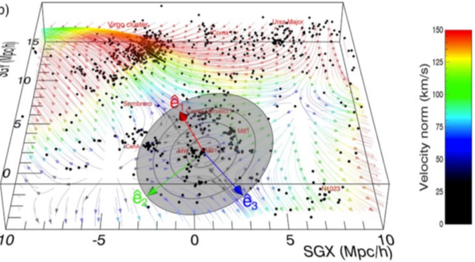
MNRAS 452, 1052–1059 (2015) doi:10.1093/mn

Planes of satellite galaxies and the cosmic web

Noam I. Libeskind,[1★] Yehuda Hoffman,[2] R. Brent Tully,[3] Helene M. Courtois,[4] Daniel Pomarède,[5] Stefan Gottlöber[1] and Matthias Steinmetz[1]







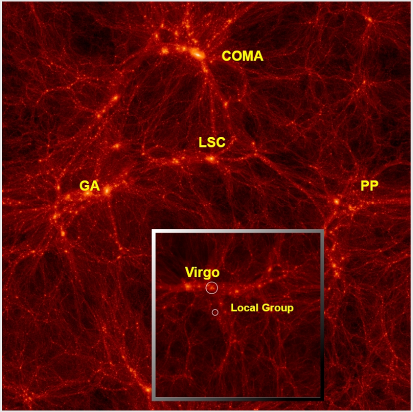
The merits of **cosmography**

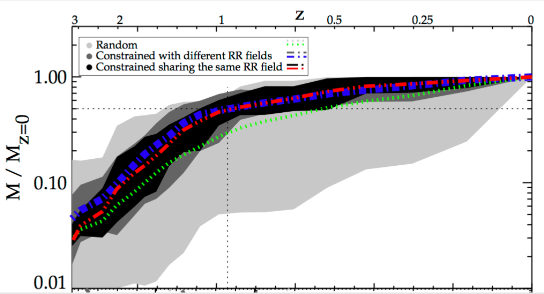
One can argue that it is a nice and noble 'hobby' - mapping the universe - that results in beautiful maps and movies.

But - the comparison of the reconstructed large scale structure with the observed distribution of galaxies constitutes a 'sanity' check on the data and its analysis. Often the the comparison uncovers 'bugs' and 'glitches' in the data.

Methodology

- Constraints: Cosmicflows (CF2, grouped data)
- Model: ΛCDM (Planck parameters)
- Assumption: linear theory (virial motions in groups & clusters are suppressed)
- Revised Zeldovich approximation (RZA): undo Zeldovich displacements
- Constrained realizations of Gaussian fields $\longrightarrow$ constrained initial condition $\longrightarrow$ constrained simulations





Virgo model

- How do we define a Virgo-like object?
- Mass: $\approx (1-5) \times 10^{14} h^{-1} \mathrm{M}_{\odot}$?
- Prediction: mass assembly history (MAH)

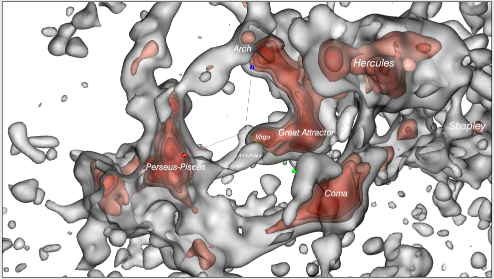
Mass assembly histories obtained with 100 random Virgo-like haloes (light grey), 15 constrained Virgo haloes from simulations built with different large scale random fields (dark grey) and 10 Virgo haloes from simulations sharing the same large scale random field (black). The mean MAH are plotted on top of the regions (green dotted line for random, blue dotdashed line for constrained with different large scale random fields and red triple dot-dashed line for constrained sharing the same large scale random field).

- Extension of the linear WF/CRs to the quasi-linear (QL) regime
- It is the first time that the actual (non-lnear) large scale density field is predicted from velocities
- A tool for studying the bias in the galaxy distribution

Methodology

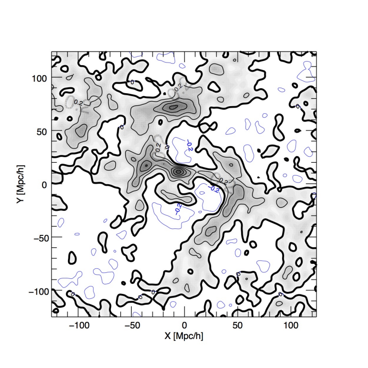
- Run an ensemble of constrained simulations.
- The ensemble samples the posterior distribution of the non-linear LSS (given the CF2 data and the prior model)
- Calculate the mean of the (log) density and the velocity field.
- Calculate scatter around the mean.
- Quasi-linear (QL) construction of the LSS
- BOX500 Mpc/h, N=512^3, 20 simulations

The QL nearby universe

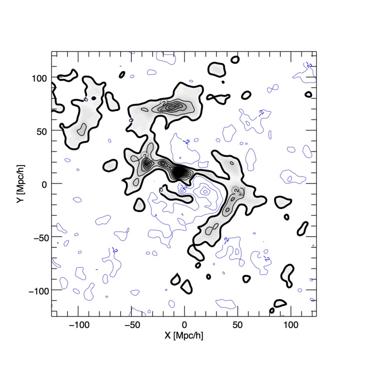


Three-dimensional visualization of the density field by means of isosurfaces. The surface shown in grey is associated with a density of $\Delta = 1.2$, while surfaces shown in nuances of red are associated with higher values of $\Delta = 1.7, 2, 2.3, 2.7, 3$. The red, green, blue $50h^{-1}\mathrm{Mpc}$-long arrows materialize the SGX, SGY, SGZ axes of the supergalactic coordinate system.

$\log \Delta$



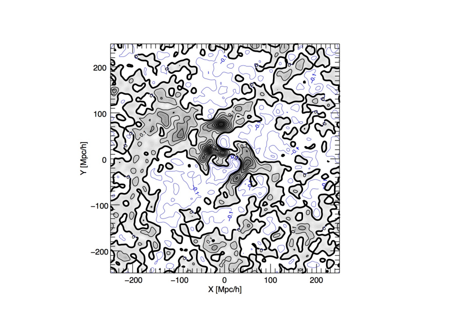
S/N



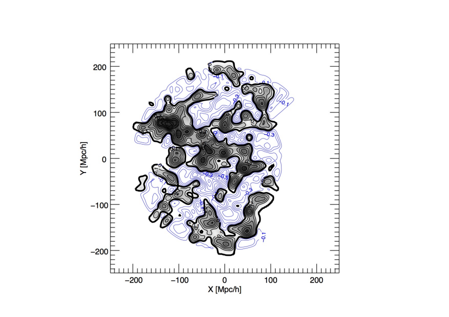
Left panel: The $\log_{10} \Delta^{QL}$ field of a slice on the Supergalactic Plane. Contour spacing of $\log_{10} \Delta^{QL}$ is 0.2. Prominent objects are theVirgo, Centaurus and Coma clusters, the Shapley concentration and Perseus - Pisces supercluster. Right panel: the signal-to-noise contour map shows the ratio of the mean to the scatter, $(\Delta^{QL} - 1)/\sigma_\Delta$, with contour spacing 2.0.

"Cosmological parameters from the comparison of peculiar velocities with predictions from the 2M++ density field" (Carrick, Turnbull, Lavaux & Hudson, MNRAS, 2015)

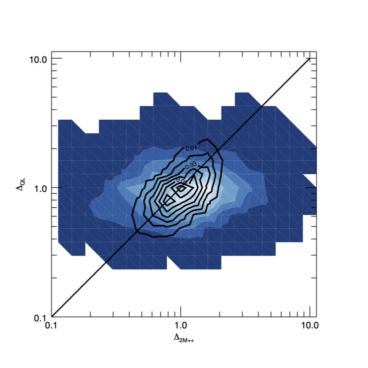
QL

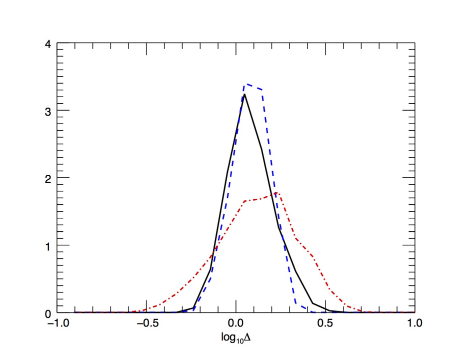


2M++



Density fields are Gaussian smoothed at $R_s = 4\sqrt{2}h^{-1}\mathrm{Mpc}$.





Non-linear bias

$$\Delta = C\Delta_{\mathrm{g}}^{\alpha}$$

$$\alpha = 0.58 \pm 0.04$$
$$C = 0.84 \pm 0.02$$

Linear bias

$$\Delta = 1 + \delta$$

$$\delta \approx \alpha\delta_{\mathrm{g}}$$

Linear bias model

$$\delta_{\mathrm{g}} = b\delta$$

$$b = \frac{1}{\alpha}$$

The Local Group factory (Carlesi et al 2016)

Constrained Local UniversE Simulations: A Local Group Factory

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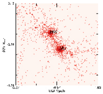
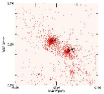
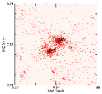
Noam I. Libeskind,[2] Sergey V. Pilipenko,[5,6] Alexander Knebe,[3,4] Hélène Courtois,[7]
R. Brent Tully,[8] Matthias Steinmetz[2]





SIMULATIONS

Name	N_{simu}	L_{box}	R_{zoom}	m_p	z_{start}
SimuLN256	100	100	NO	5.26×10^9	60
SimuLN512	12	100	NO	6.57×10^8	80
SimuLGzoom	300	100	12	6.57×10^8	80



RECOVERY OF THE LOCAL NEIGHBORHOOD

	mean	σ
$\mathbf{e}_1 \cdot \mathbf{e}_1^{WF}$	0.95	0.11
$\mathbf{e}_2 \cdot \mathbf{e}_2^{WF}$	0.93	0.15
$\mathbf{e}_3 \cdot \mathbf{e}_3^{WF}$	0.97	0.08

(a)

	simu	*obs*
λ_1	0.174 ± 0.062	0.148 ± 0.038
λ_2	0.052 ± 0.075	0.051 ± 0.039
λ_3	-0.270 ± 0.074	-0.160 ± 0.033

(b)

Figure 4. Particle densities in a $5h^{-1}$ Mpc side slice of thickness $\pm 2h^{-1}$ Mpc showing the candidates $M31$ and MW in a single realisation, along the $X-Y$, $X-Z$ and $Y-Z$ planes.

Aim: To run a very large number of constrained simulations that 'mimic' the nearby universe.

Motivation: Statistics of look-alike Local Groups

Local Group model

What is a LG?

- Simplest model: two halos, distance $d = (0.35 - 0.70)h^{-1}\mathrm{Mpc}$, physical radial velocity $v_r = (-135 \ - \ -80)\,\mathrm{km\ s^{-1}}$, isolation
- More advanced: add tangential velocity (v_{tan})
- Even more advanced and less observationally motivated: add mass
- More physical: $(M,\ d,\ v_r,\ v_{tan}) \ \rightarrow$ (energy, angular momentum) i.e. an orbit.
- Observationally constrained physical model: fix the phase on the orbit (to get the correct $d,\ v_r,\ v_{tan}$)
- Add galaxy formation considerations: e.g. quite recent merging history, disks

Bayesian inference: posterior distribution

$$P_{\text{constrained}}\left(\mathrm{X}_{\mathrm{LG}} \mid \Lambda\mathrm{CDM}, \mathrm{Cosmicflows\ data},\ \mathrm{LG\ model}\right)$$

$$P_{\text{random}}\left(\mathrm{X}_{\mathrm{LG}} \mid \Lambda\mathrm{CDM},\ \mathrm{LG\ model}\right)$$

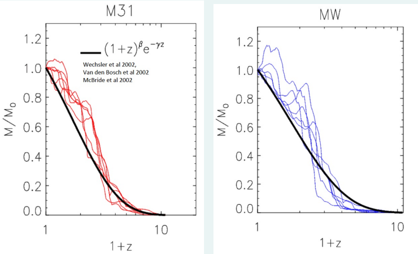
$$\mathsf{X}_{\mathrm{LG}} = \text{mass, tangential velocity, merging history, ... of the LG}$$

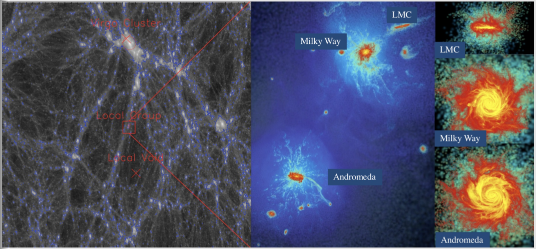
The sampling of the posterior distribution function is done by looking for pairs of halos that obey the LG model at the LG position in constrained or random simulations.

HESTIA project - constrained zoom hydro simulations of the Local Group (Libeskind +)

m CLUES + Springer et al: High resolution hydro (AREPO/Auriga galaxy formation code) zoom constrained simulations of the LG.

mass assembly history (MAH)





Numerical model: BOX=$100h^{-1}\mathrm{Mpc}$, 4 simulations with $N = 4096^3$ and 4 with $N = 8192^3$ particles corresponding to $m_{DM} \sim 1.2 \times 10^6 h^{-1}\mathrm{M}_\odot$ and $1.5 \times 10^5 h^{-1}\mathrm{M}_\odot$ (Planck ΛCDM model).

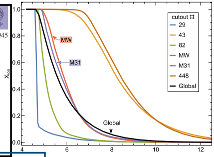
Data: Cosmicflows2

Reionization of the local universe

Monthly Notices of the ROYAL ASTRONOMICAL SOCIETY
MNRAS 480, 1740–1753 (2018) doi:10.1093/mnras/sty1945
Advance Access publication 2018 July 20

Suppression of star formation in low-mass galaxies caused by the reionization of their local neighbourhood

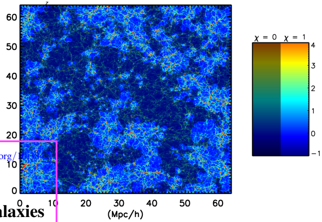
Taha Dawoodbhoy,[1★] Paul R. Shapiro,[1★] Pierre Ocvirk,[2] Dominique Aubert,[2] Nicolas Gillet,[2,3] Jun-Hwan Choi,[1] Ilian T. Iliev,[4] Romain Teyssier,[5] Gustavo Yepes,[6] Stefan Gottlöber,[7] Anson D'Aloisio,[1,8] Hyunbae Park[1,9] and Yehuda Hoffman[10]



MNRAS 000, 1–18 (2018) Preprint 29 November 2018 Compiled using MNRAS LATEX style file v3.0

Cosmic Dawn II (CoDa II): a new radiation-hydrodynamics simulation of the self-consistent coupling of galaxy formation and reionization

Pierre Ocvirk[1], Dominique Aubert[1], Jenny G. Sorce[1,2,3], Paul R. Shapiro[4], Nicolas Deparis[1], Taha Dawoodbhoy[4], Joseph Lewis[1], Romain Teyssier[5], Gustavo Yepes[6,7], Stefan Gottlöber[3], Kyungjin Ahn[8], Ilian T. Iliev[9], Yehuda Hoffman[10].



Astrophysical Journal Letters, 856:L22 (6pp), 2018 April 1 https://doi.org/

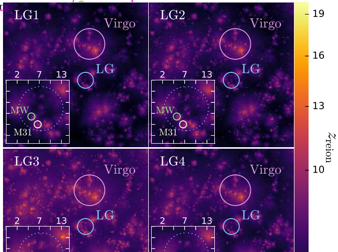
The Inhomogeneous Reionization Times of Present-day Galaxies

Dominique Aubert[1], Nicolas Deparis[1], Pierre Ocvirk[1], Paul R. Shapiro[2], Ilian T. Iliev[3], Gustavo Yepes[4], Stefan Gottlöber[5], Yehuda Hoffman[6], and Ror

MNRAS 477, 867–881 (2018) doi:10.1093/mnras/sty494 Advance Access publication 2018 February 27

Reionization of the Milky Way, M31, and their satellites – I. Reionization history and star formation

Keri L. Dixon,[1,2] Ilian T. Iliev,[2] Stefan Gottlöber,[3] Gustavo Yepes,[4,5,6] Alexander Knebe,[4,5,6] Noam Libeskind[3] and Yehuda Hoffman[7]



Cosmic-Ray Anisotropy from Large Scale Structure

Mon. Not. R. Astron. Soc. **000**, 1–?? (2002)   Printed 21 November 2018   (MN LaTeX style file v2.2)

Cosmic-Ray Anisotropy from Large Scale Structure and the effect of magnetic horizons

N. Globus,[1⋆] T. Piran,[1] Y. Hoffman,[1] E. Carlesi[2], D. Pomarède[3]

ABSTRACT

Motivated by the $\sim 7\%$ dipole anisotropy in the distribution of ultra-high energy cosmic-rays (UHECRs) above 8 EeV, we explore the anisotropy induced by the large scale structure, using constrained simulations of the local Universe and taking into account the effect of magnetic fields. The value of the intergalactic magnetic field (IGMF) is critical as it determines the UHECR cosmic horizon. We calculate the UHECR sky maps for different values of the IGMF variance and show the effect of the UHECR horizon on the observed anisotropy. The footprint of the local ($\lesssim$ 350 Mpc) Universe on the UHECR background, a small angular scale enhancement in the Northern Hemisphere, is seen. At 11.5 EeV (the median value of the energy bin at which the dipole has been reported), the LSS-induced dipole amplitude is $A_1 \sim 10\%$, for IGMF in the range [0.3-3] nG for protons, helium and nitrogen, compatible with the rms value derived from the cosmic power spectrum. However at these energies the UHECRs are also influenced by the Galactic Magnetic Field (GMF) and we discuss its effect on the LSS-induced anisotropy.

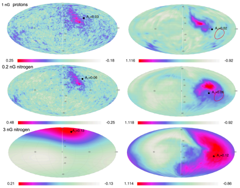


Figure 6. Sky maps, in Galactic coordinates, of the LSS-induced UHECR anisotropy taking into account the effect of the Galactic magnetic field of Jansson & Farrar (2012a). Left, from top to bottom: the LSS-induced UHECR anisotropy for protons at 11.5 Eev in 1 nG IGMF, nitrogen in 0.2 and 3 nG IGMF respectively. Right: the anisotropy after reconstruction by the GMF of Jansson & Farrar (2012a). The amplitude A_1 and direction of the dipole are marked by the black dot. The observed Auger dipole direction is figured by the red circle.

- The initial conditions of the Near Field are very well constrained by the CLUES/Cosmicflows machinery.
- CLUES is the near field cosmology on the computer - numerical laboratory for experimenting with the physics of galaxy formation.
- The constrained simulations test the Copernican hypothesis on the nature of the near-field.

TODA (thank you) Ofer for an inspiring and enjoyable collaboration.