The Large-Scale Environments

The large-scale distribution of baryons inside the cosmological hydrodynamical simualtions.

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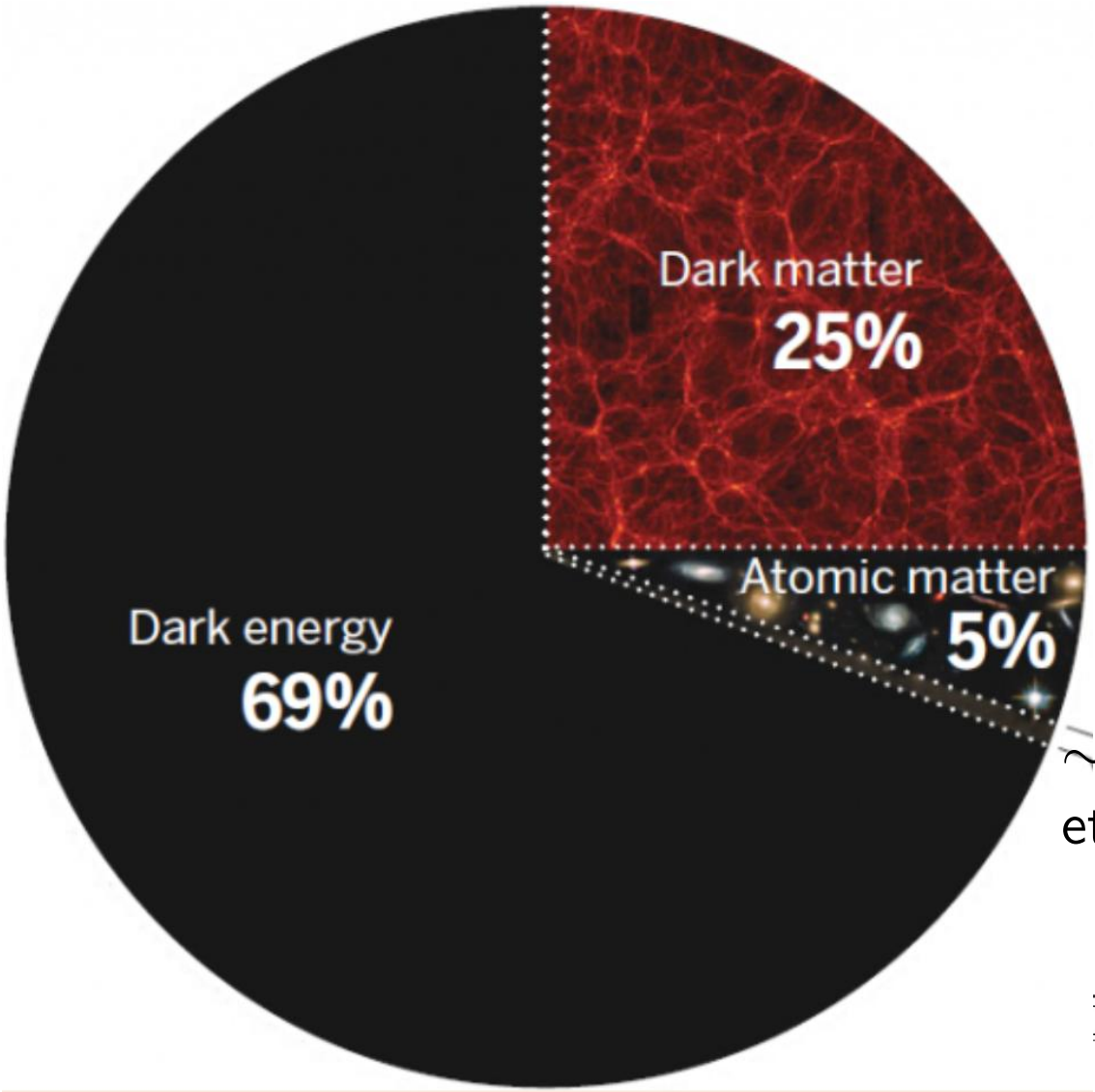
The HUBS workshop, @ Shanghai.
October, 16, 2018

[1] https://weiguangcui.github.io

Background:

The content of the Universe:



$\sim$1% of neutrinos, etc.

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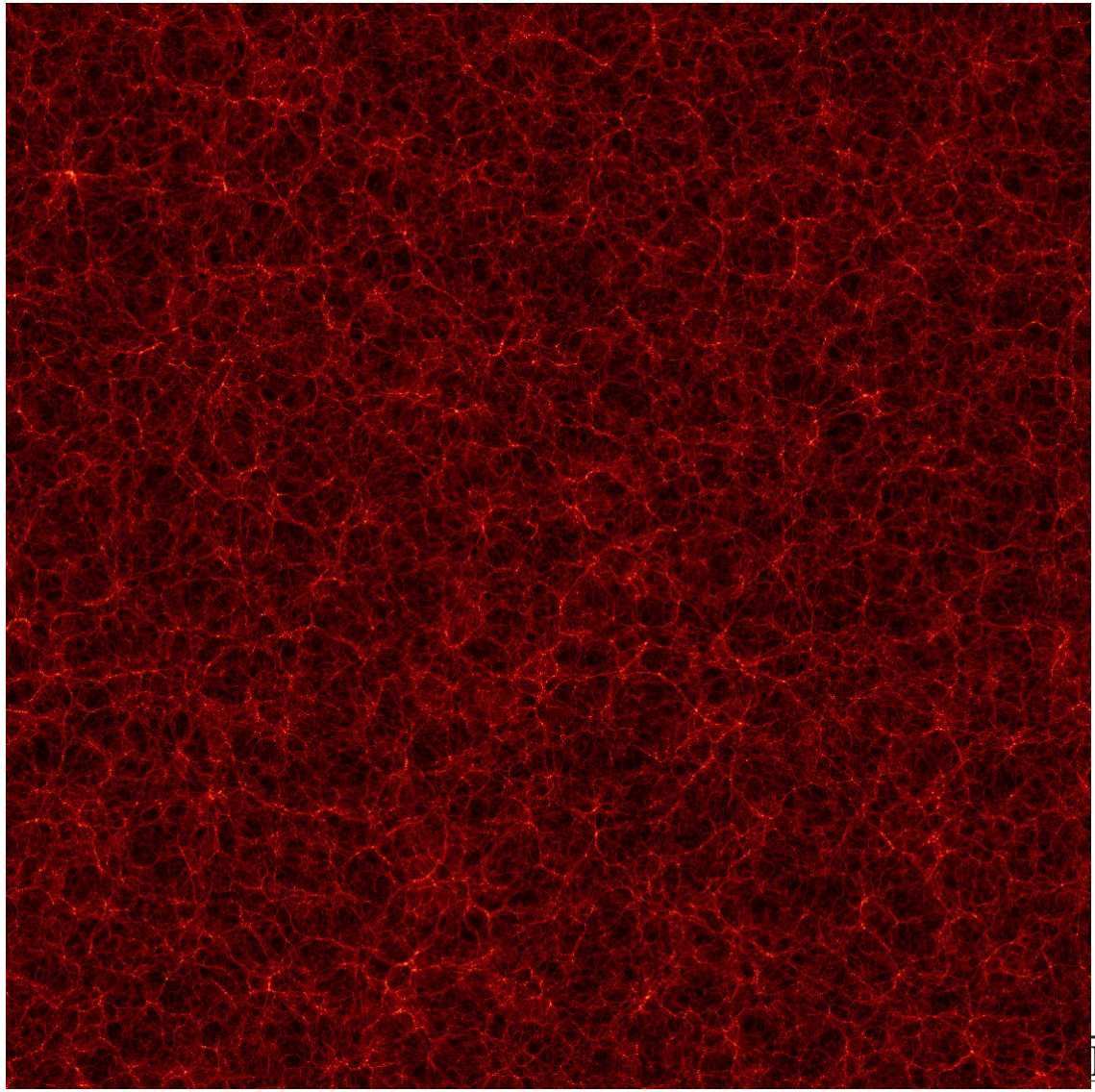
Background: the distribution of dark matter at large scale



Credit: MultiDark Planck simulation

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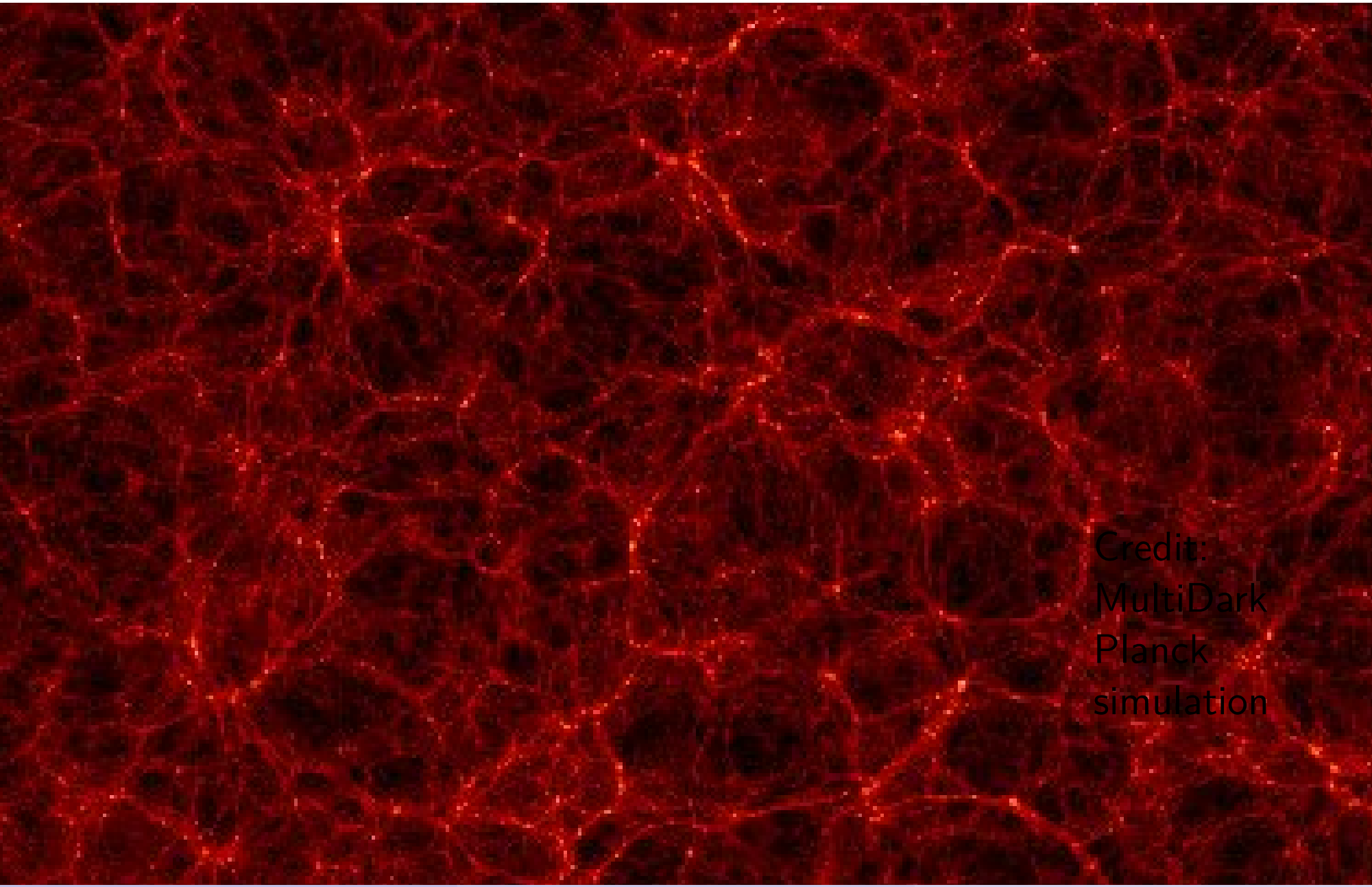

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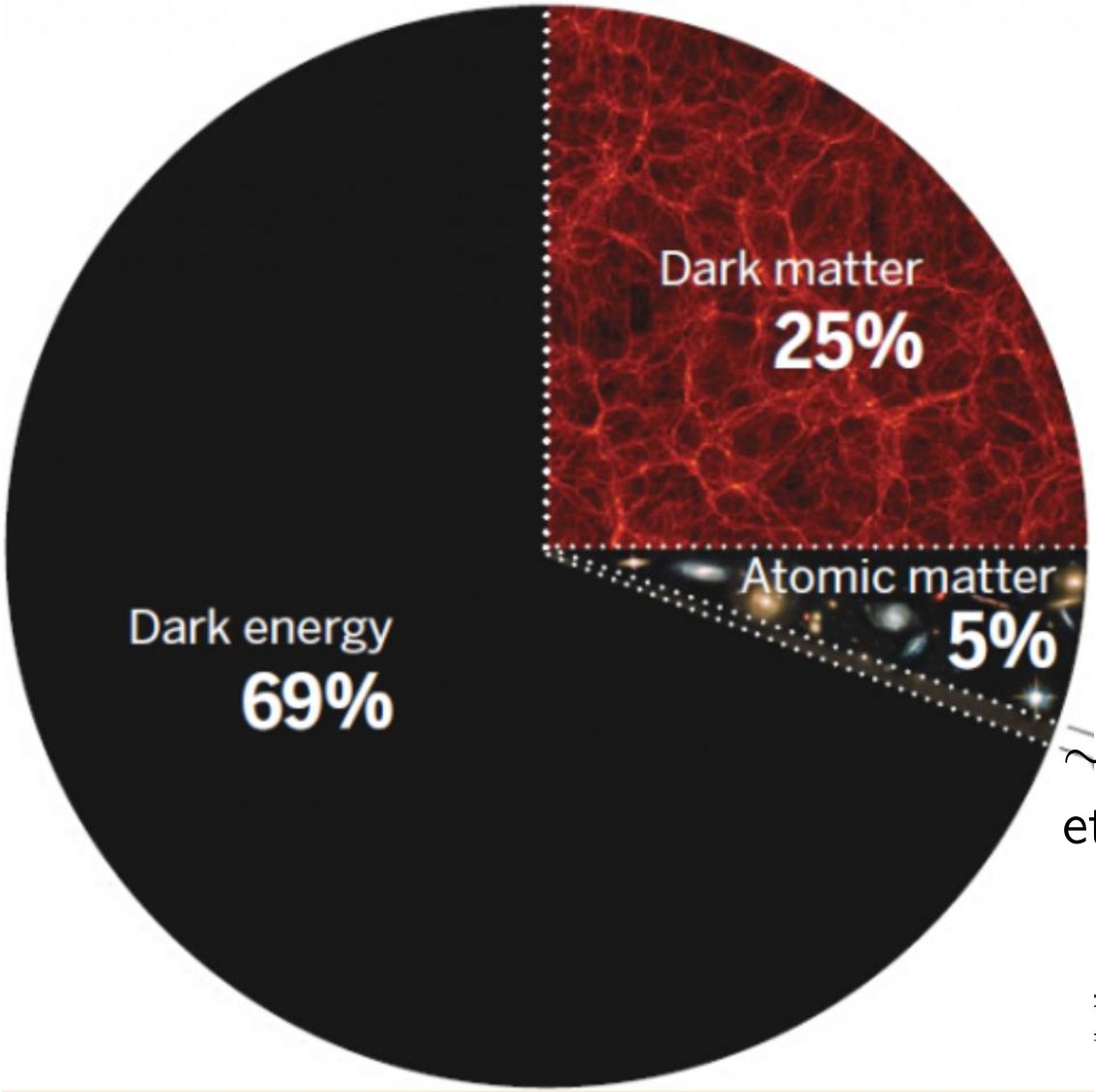

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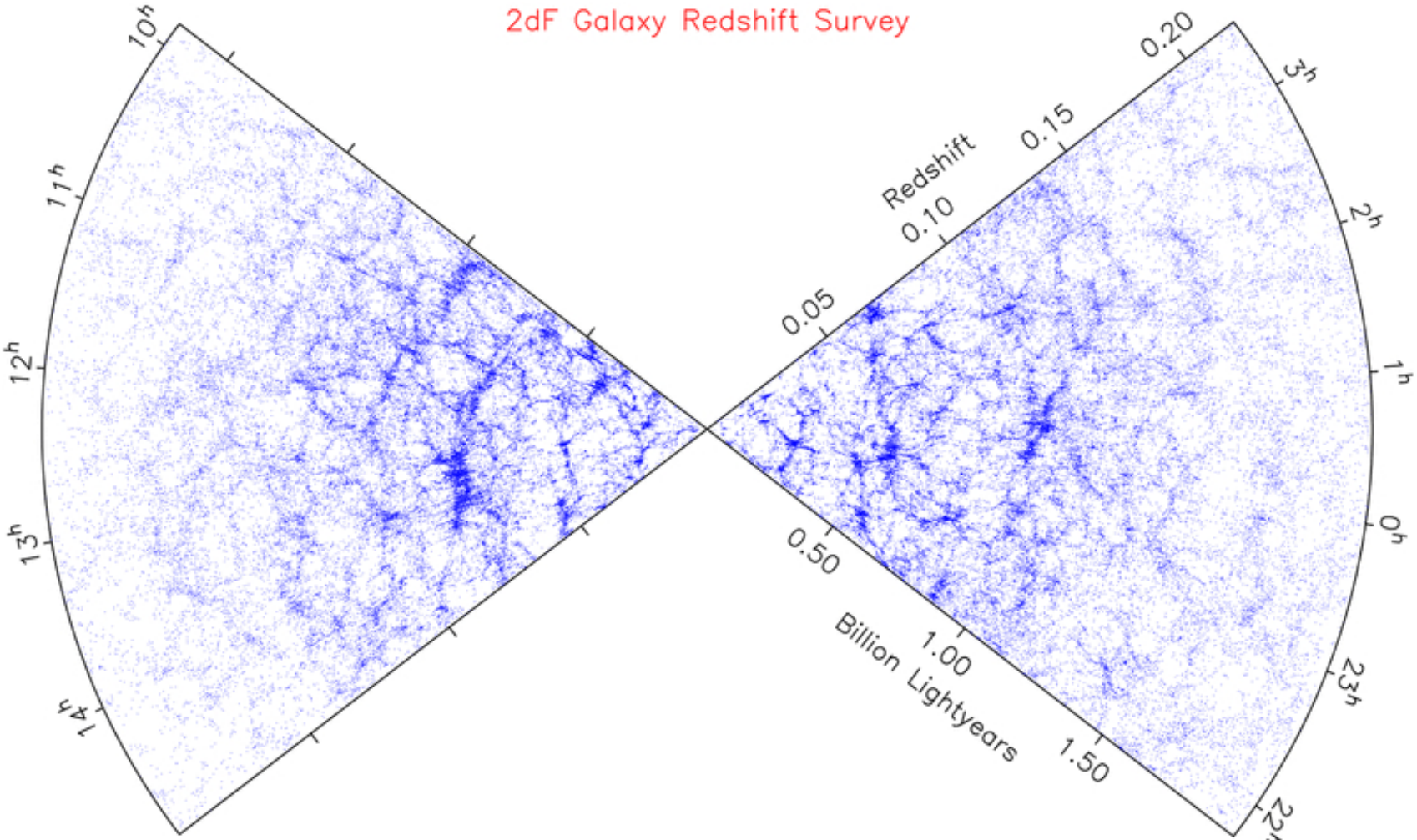
Background: the distribution of galaxies at large-scale



Credit: Yang et al. 2005

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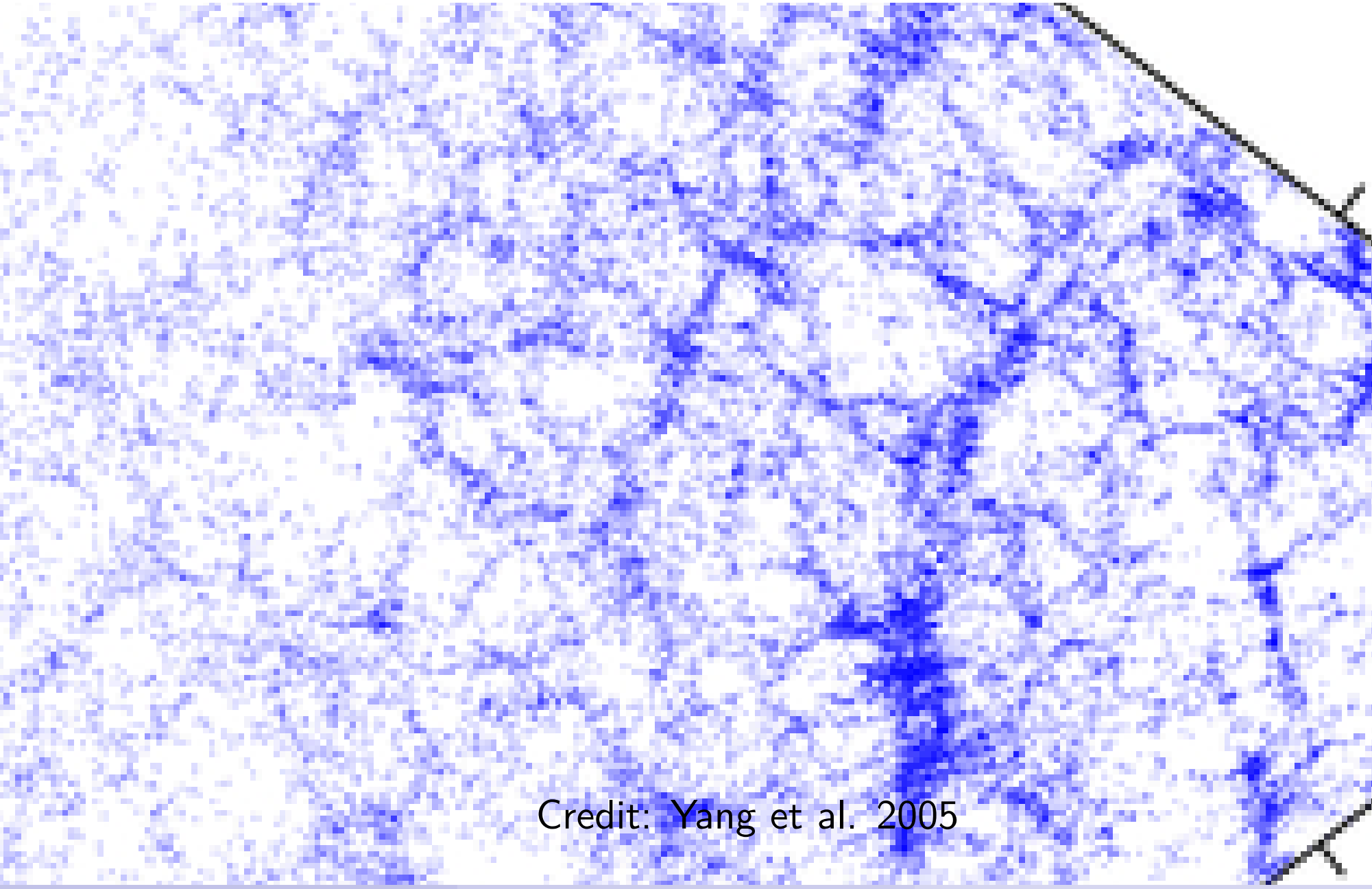

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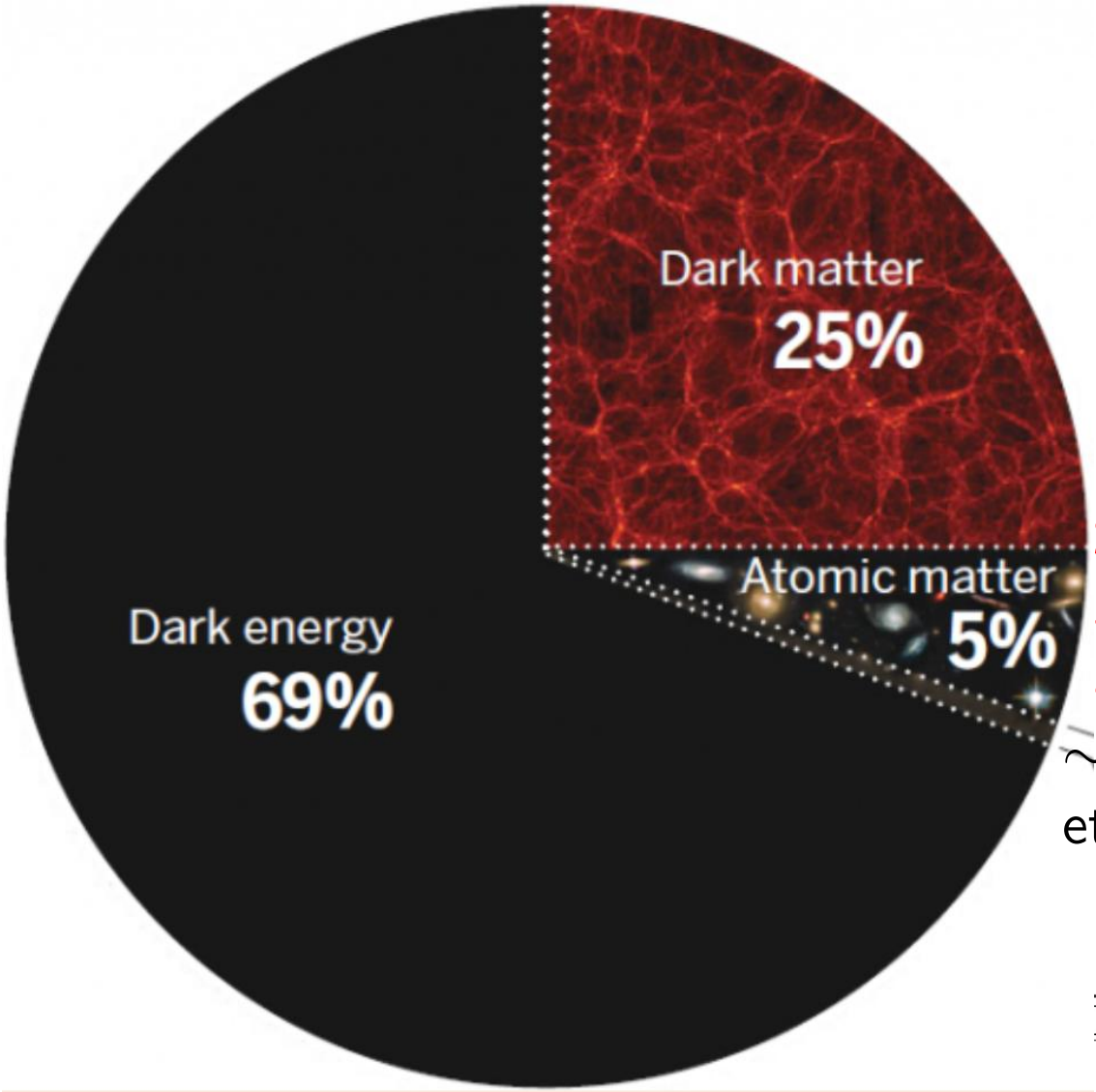
Background: the fractions

The content of the Universe:



Stars only account for $\sim 0.07\%$

$\sim 1\%$ of neutrinos, etc.

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- What does the simulation say about the baryon distribution?
- Conclusion and future prospects.

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The cosmological hydrodynamical simulations

Three versions of simulations with different sets of baryonic models are used for this study:

- RDM – dark-matter-only simulation;
- CSF – gas Cooling, Star formation and Supernovae feedback;
- AGN – additional BH evolution and feedback are also included.

Table: Parameters of the Three Hundred simulations

Parameter	Value	Description
Ω_M	0.24	Total Matter density parameter
Ω_B	0.041	Baryon density parameter
Ω_Λ	0.76	Cosmological Constant density parameter
h	0.73	Hubble constant in units of 100 km/s/Mpc
σ_8	0.8	Normalization of Power spectrum
n_s	0.96	Power index
ϵ_{phys}	7.5	Plummer equivalent softening in $h^{-1}\,\mathrm{kpc}$
Box size	410	[$h^{-1}\,\mathrm{Mpc}$] The simulation box size on one side
Particle mass	7.6(35.4)	[$10^8\ h^{-1}\,\mathrm{M}_\odot$] gas (DM) particle mass

Details can be found in Cui et al. 2014.

The overall baryon fractions

Following Dave et al. 2001, gas is separated into:

Hot gas: $T > 10^7$ K

WHIM: $10^5 > T > 10^7$ K

	f_{hotgas}	f_{WHIM}	f_{star}
Nicastro et al. 2018 ($z < 0.5$)	$\sim$5%	$\sim$24 -55 %	$\sim$7 %
CSF ($z = 0$)	4.6%	38.3%	6.5%
AGN ($z = 0$)	4.6%	41.3%	3.2%
CSF ($z = 0.6$)	1.1%	29.7%	4.2%
AGN ($z = 0.6$)	2.4%	34.9%	2.5%

Table: The mass fractions are with respect to the cosmic baryon fraction.

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The classification methods – Vweb and Pweb[2]

The re-scaled Poisson equation: $\Delta^2\phi = \delta$ with δ the dimensionless matter overdensity and ϕ is the potential.

$\lambda_{th} = 0.01$ for Pweb; $\lambda_{th} = 0.1$ for Vweb

[2] Also called T-web

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Pweb:

The tidal tensor, $T_{\alpha\beta}$, is defined by the Hessian of the gravitational potential ϕ: $T_{\alpha\beta} = \frac{\partial^2\phi}{\partial r_\alpha \partial r_\beta}$.

Tweb :

The shear tensor, which is rewritten as $\Sigma_{\alpha,\beta} = -\frac{1}{2}(\frac{\partial v_\alpha}{\partial r_\beta} + \frac{\partial v_\beta}{\partial r_\alpha})/H_0$

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The three eigenvalues $\lambda_1 > \lambda_2 > \lambda_3$ are used to determine the large-scale environments:

- Voids: if $\lambda_1 < \lambda_{th}$
- Sheets: if $\lambda_1 >= \lambda_{th} > \lambda_2$
- Filaments: if $\lambda_2 >= \lambda_{th} > \lambda_3$
- Knots: $\lambda_3 >= \lambda_{th}$

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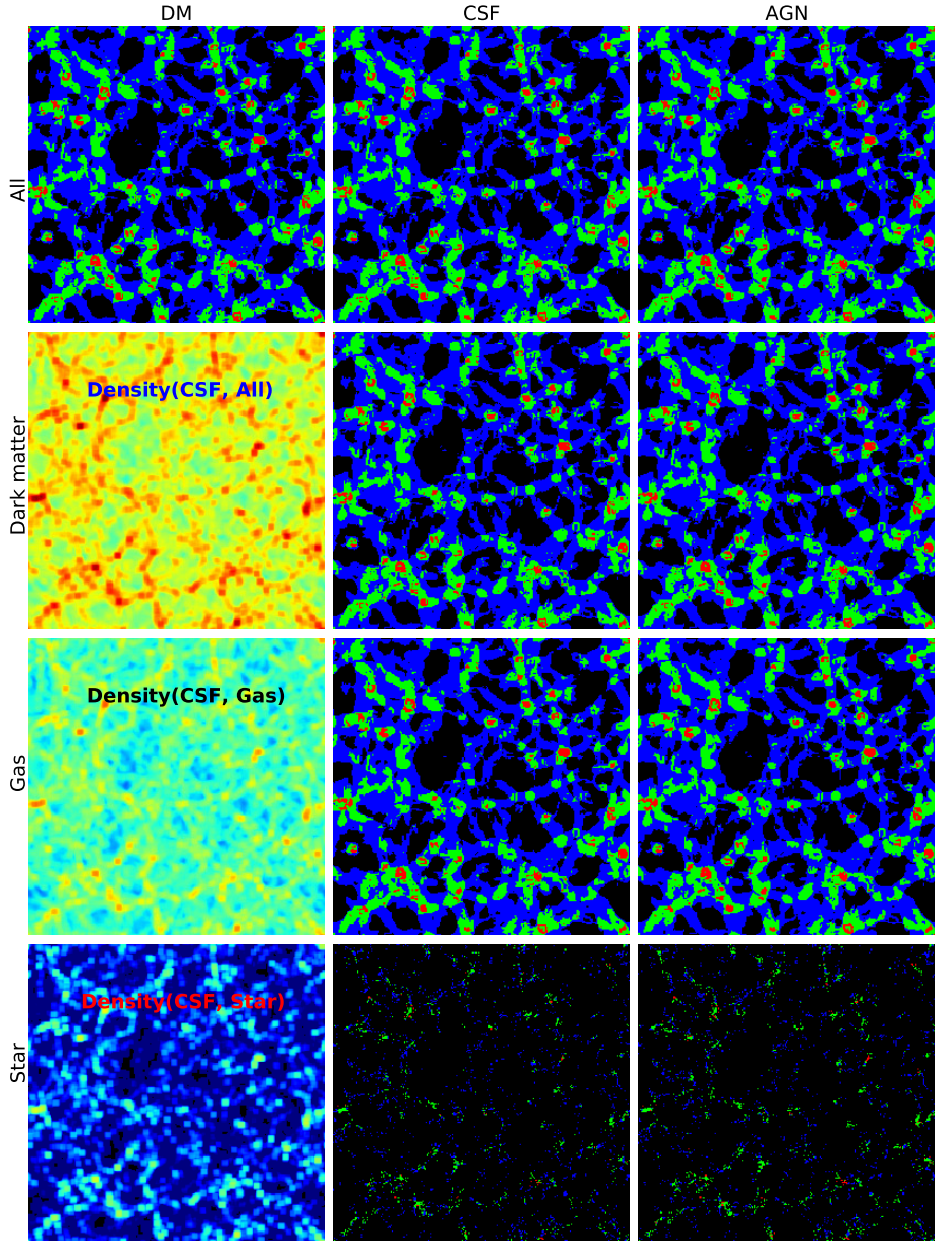
An illustration at z = 0



Cui et al. 2018, Paper I, z=0, Vweb

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The total mass fractions in different large-scale structures

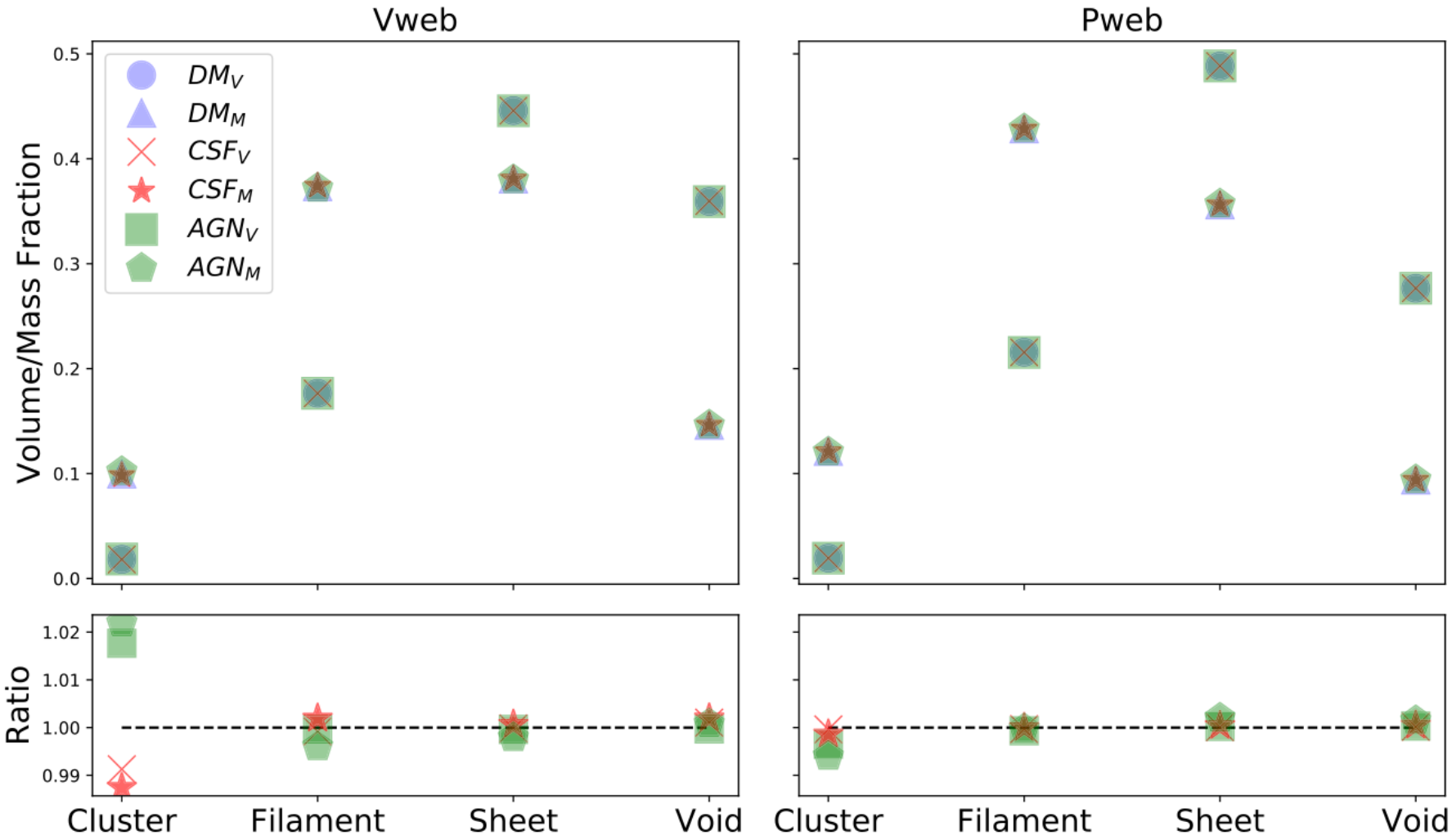

Figure: The mass and volume fractions of these large-scale environments, Cui et al. 2018, Paper I

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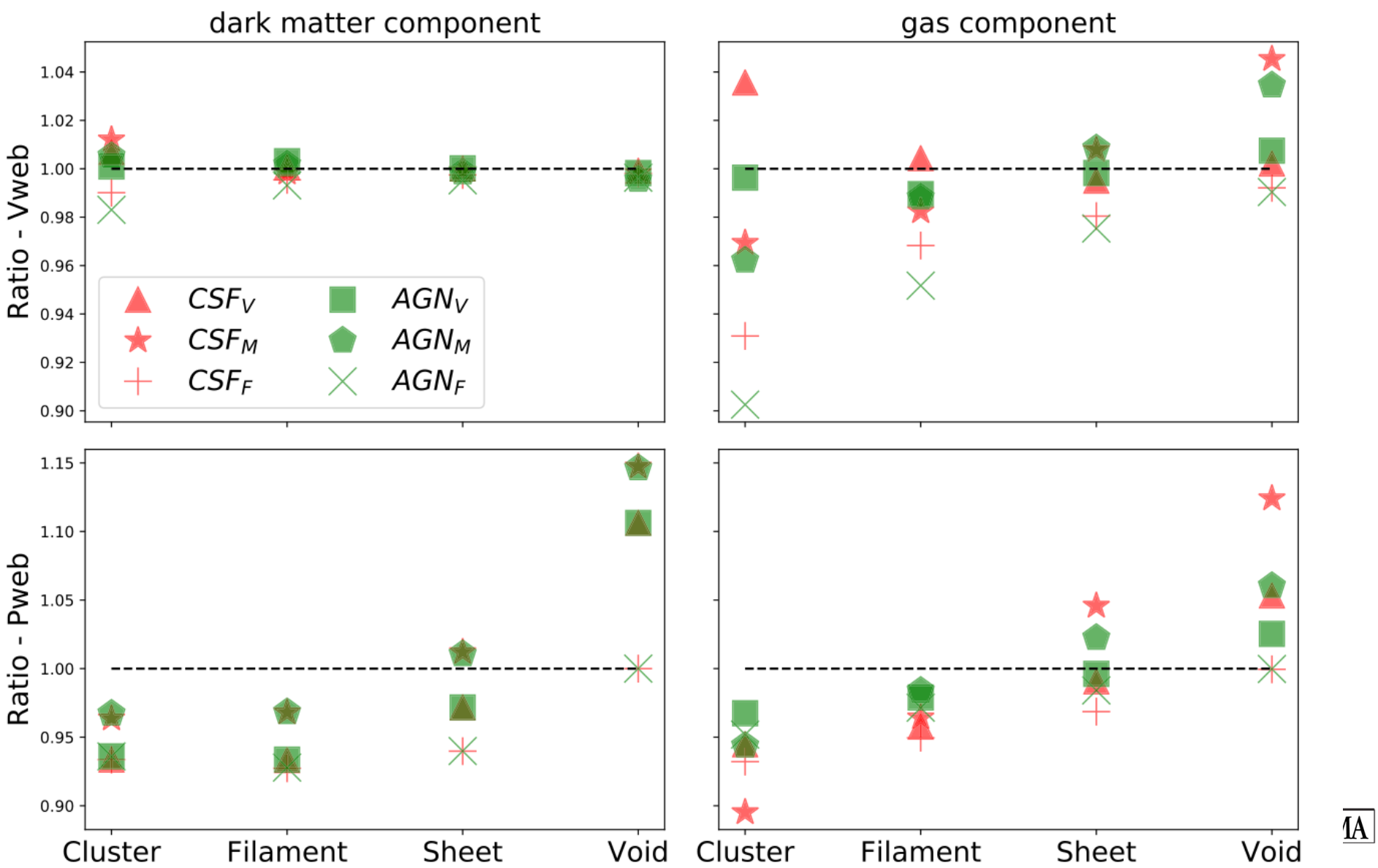


Some preliminary results from Paper II

An illustration: the redshift evolution

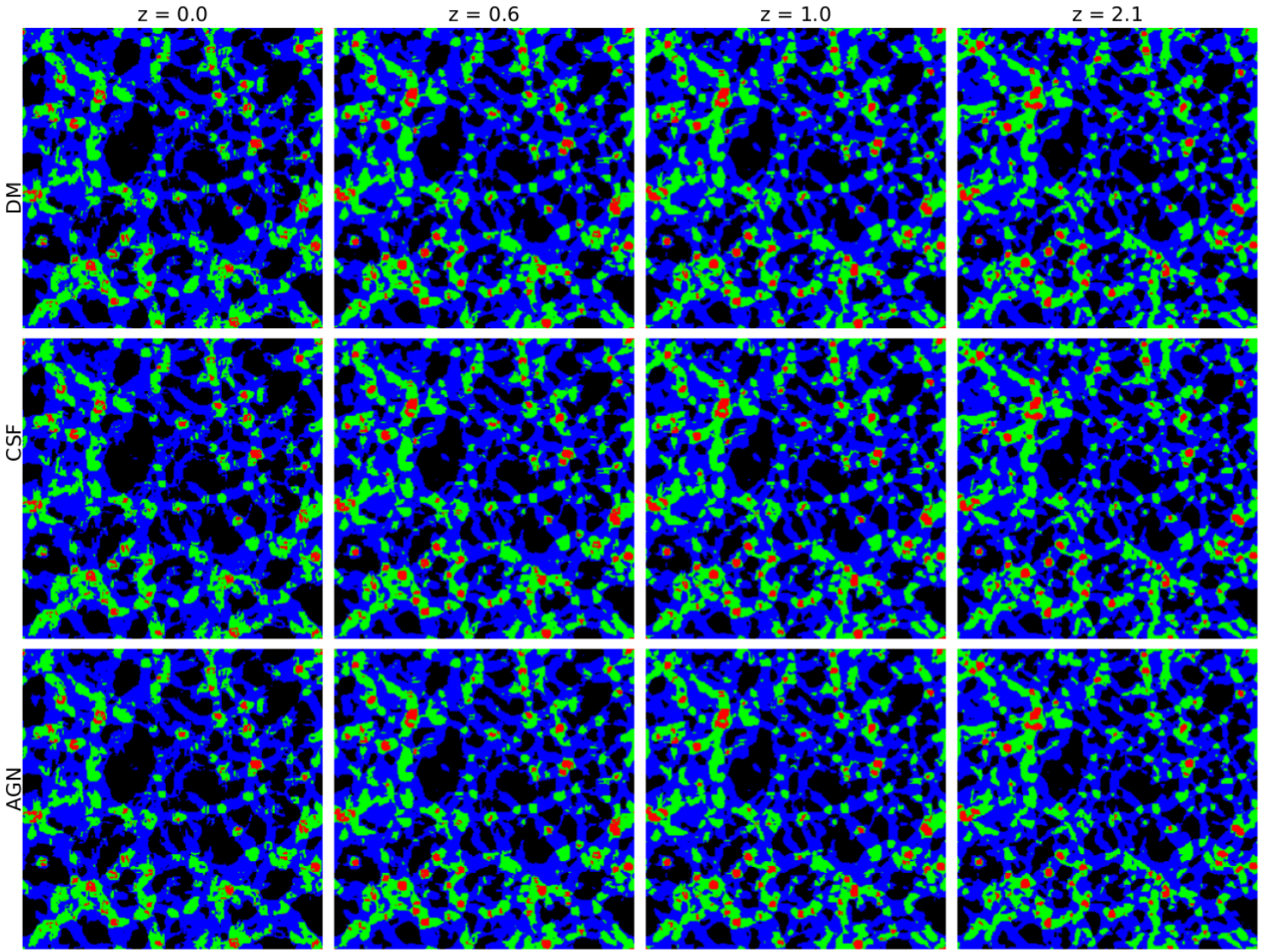


Figure: large-scale environments classified by Vweb

The fraction evolution

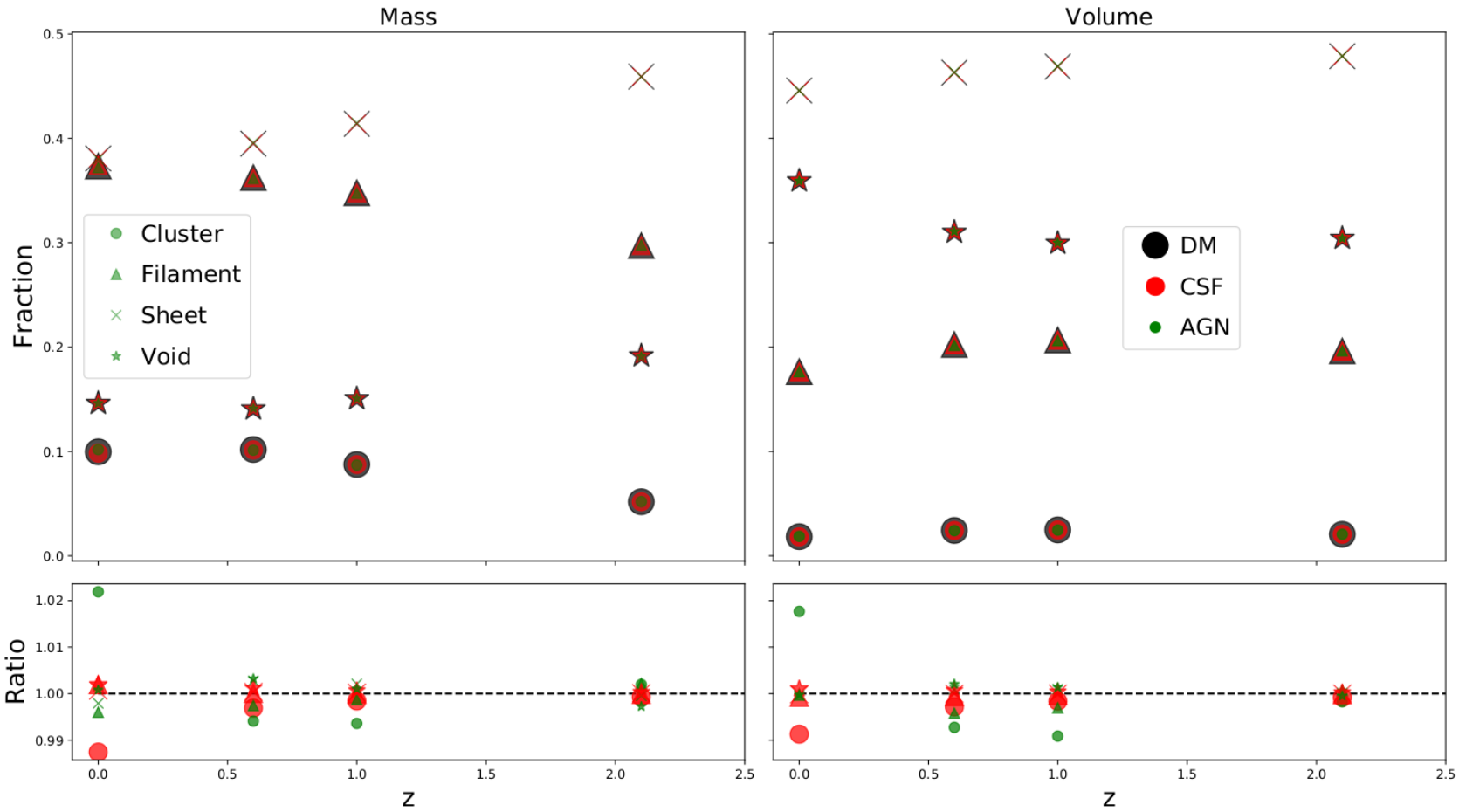


Figure: The mass (left) and volume (right) fractions evolution from the Vweb method. See Zhu & Feng, 2017 for similar results.

The baryonic web

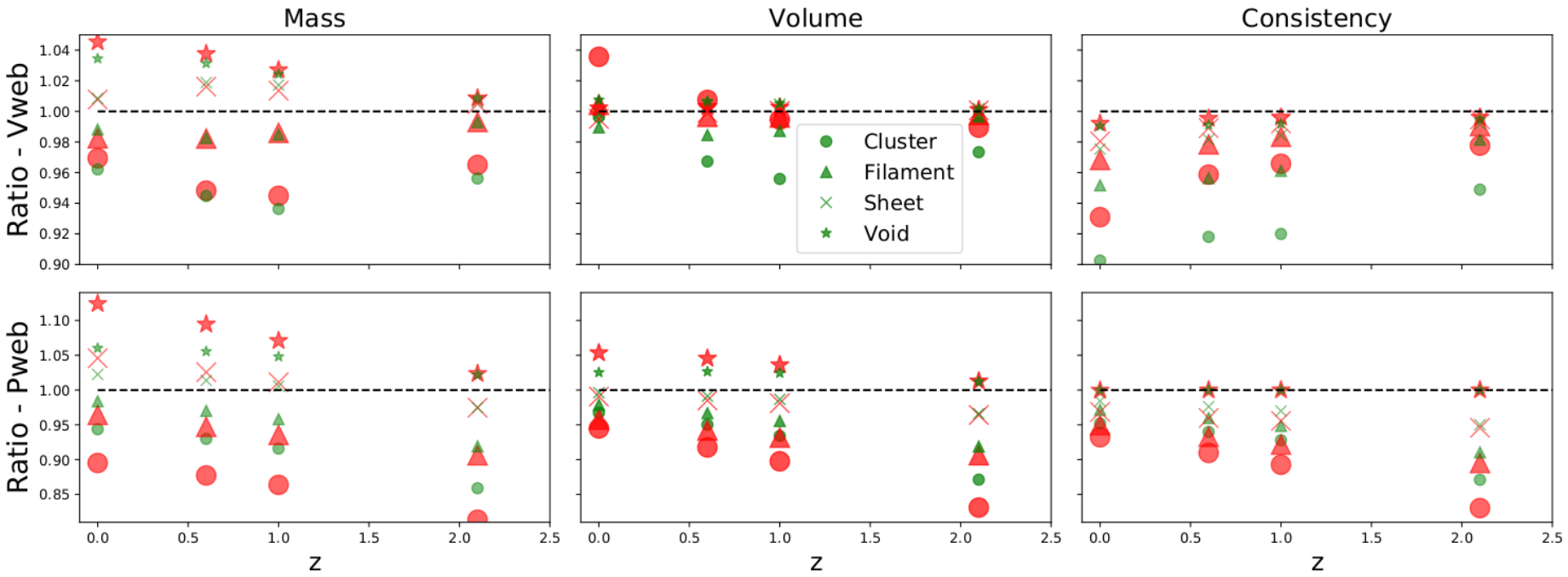
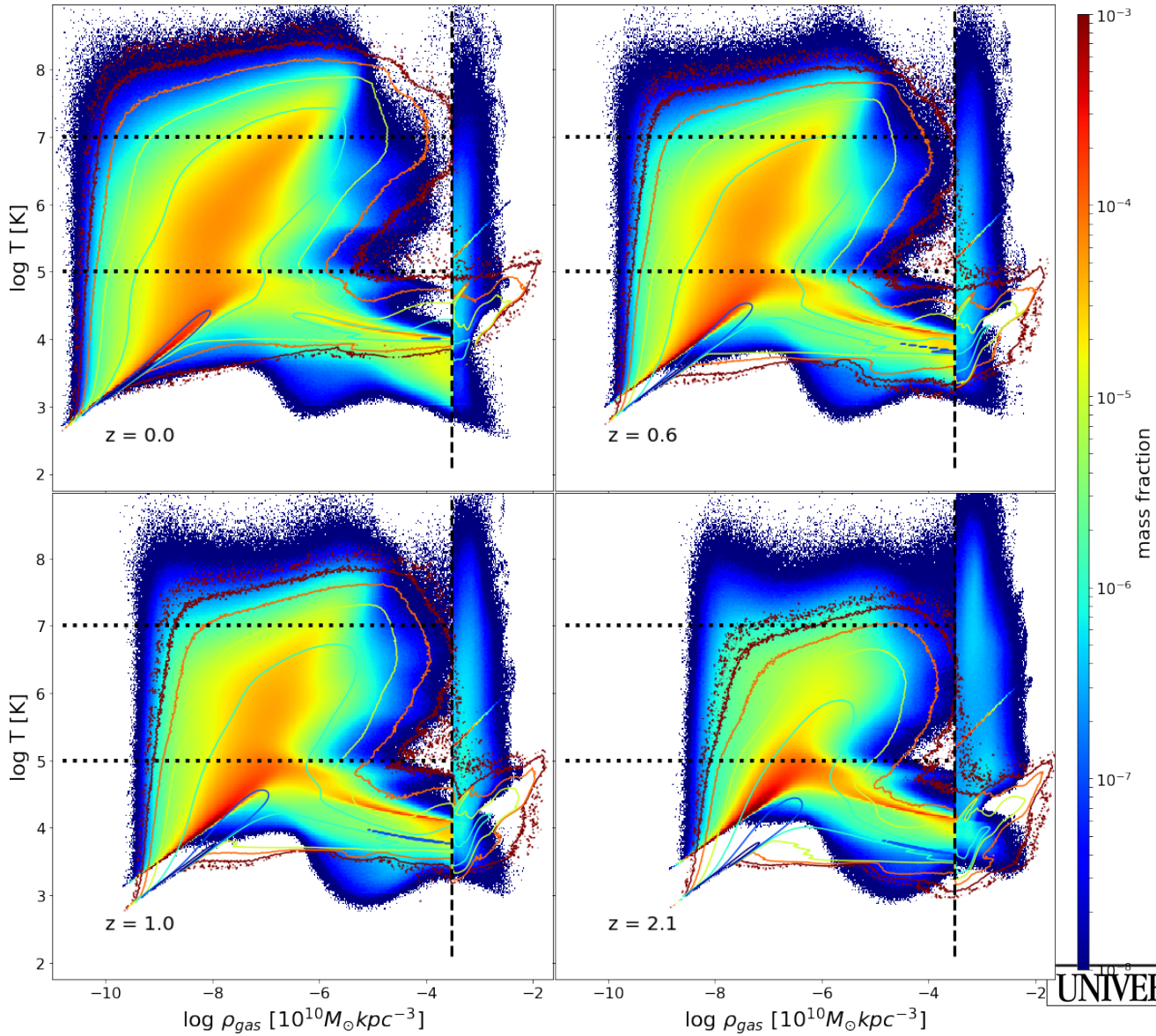


Figure: The differences between the large-scale structures classified by gas and total matter.

The gas density-temperature diagram



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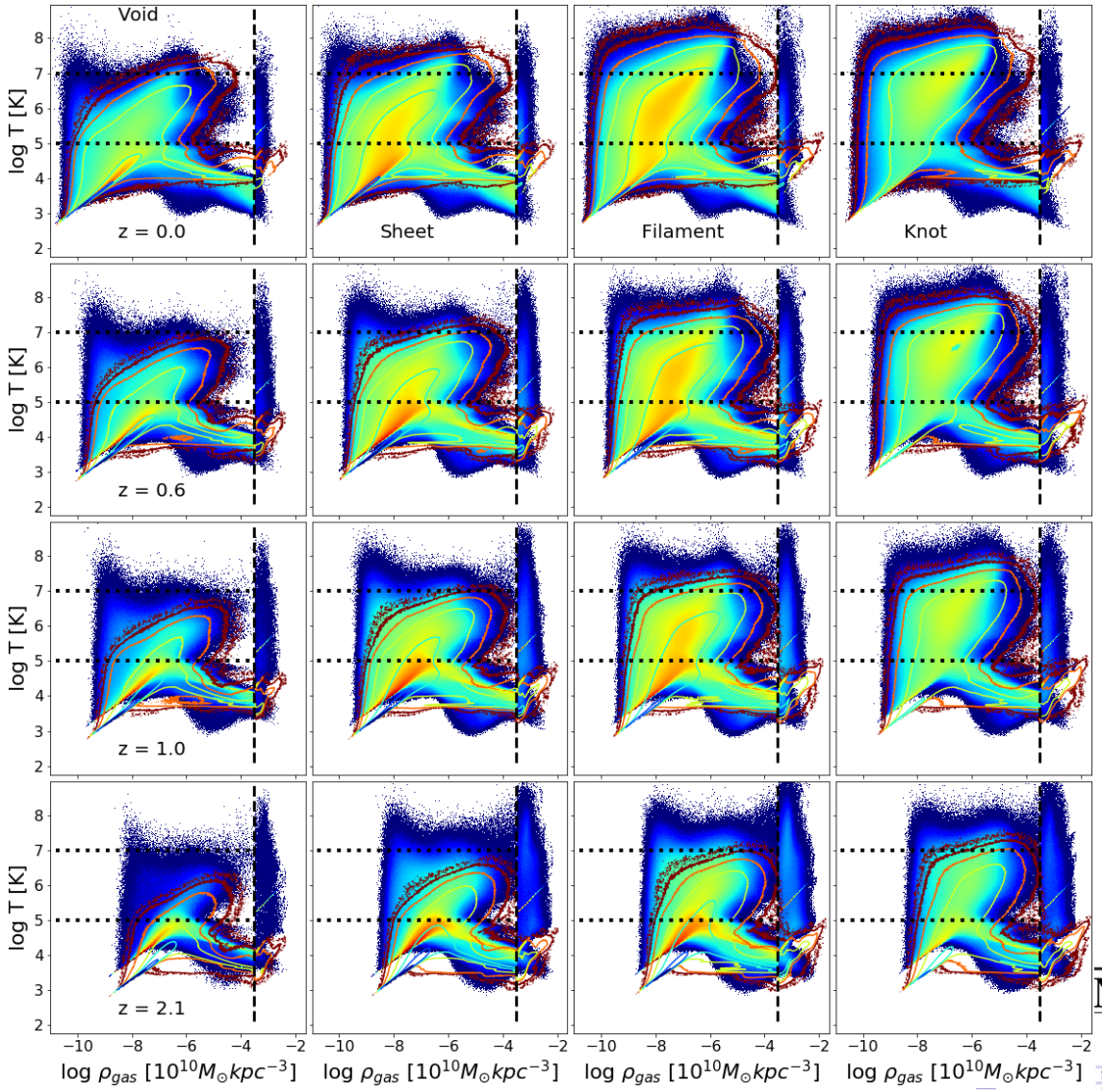
The gas density-temperature diagram in different large-scale environments



The fractions in different gas components.

Table: The distribution of different baryon components in different environments. The AGN results are the first value with the CSF results follow in the bracket.

	Voids	Sheets	Filaments	Knots
		$z = 0$		
$f_{M,gas}$	0.15 (0.16)	0.38 (0.39)	0.37 (0.36)	0.1 (0.09)
$f_{M,star}$	0.08 (0.06)	0.33 (0.29)	0.44 (0.48)	0.15 (0.17)
$f_{M,hotgas}$	0.002 (0.003)	0.04 (0.05)	0.46 (0.50)	0.49 (0.45)
$f_{M,WHIM}$	0.05 (0.06)	0.30 (0.31)	0.51 (0.50)	0.14 (0.13)
		$z = 0.6$		
$f_{M,gas}$	0.14 (0.14)	0.39 (0.39)	0.37 (0.36)	0.11 (0.11)
$f_{M,star}$	0.05 (0.03)	0.28 (0.22)	0.47 (0.48)	0.21 (0.27)
$f_{M,hotgas}$	0.001 (0.000)	0.01 (0.003)	0.23 (0.15)	0.76 (0.85)
$f_{M,WHIM}$	0.03 (0.03)	0.25 (0.23)	0.53 (0.52)	0.20 (0.22)

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Conclusion

- The baryon models have a weak impact on the matter distributions at large scale.
- Gas is a unbiased tracer of dark matter for these large-scale structures, especially filament.
- Although the whole gas is almost equally assigned into sheet and filaments, the most WHIM is located in the filament structures while the hot gas is basically located in filaments and knots.

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Future prospects

Connecting hydrodynamical simulations with observations through mock images.

- Optical: pymgal
- Xray: pymxc
  spectrum is coming from Xspec library, interpolated with gas properties from hydrosimulations to produce the SIMPUT format, this file will use SIXTE (a monte-carlo simulation toolkit for the Athen XIFU) to produce the eventlist.
- SZ: pymsz
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My personal interests to HUBS:

1. theoretical analysis pipeline with pymxc.
2. Using HUBS to constrain cosmology models/parameters.

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