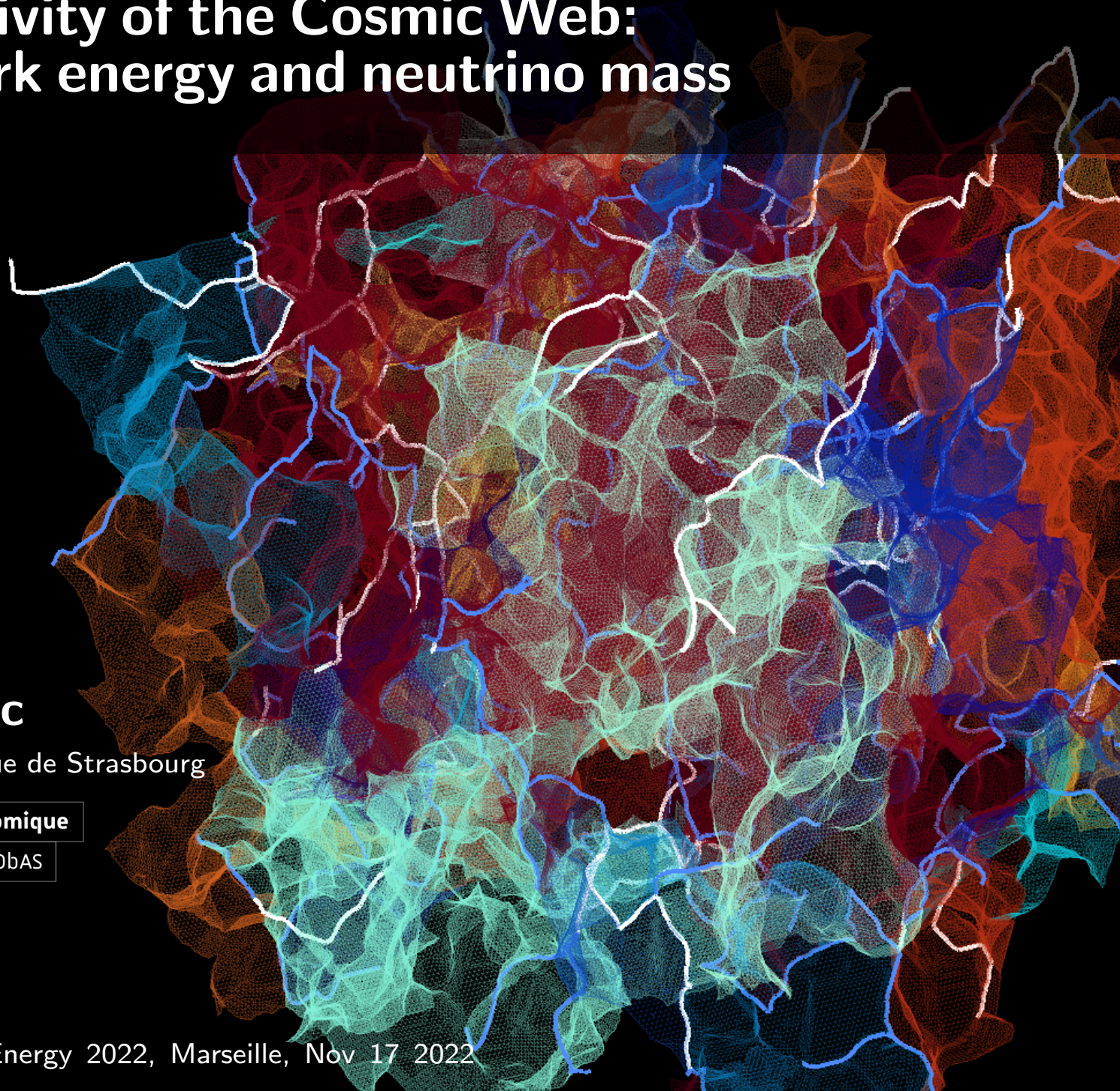
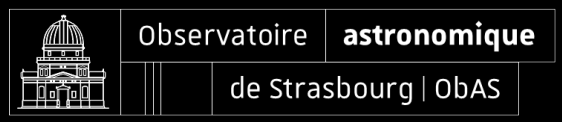
The connectivity of the Cosmic Web: impact of dark energy and neutrino mass



Katarina Kraljic

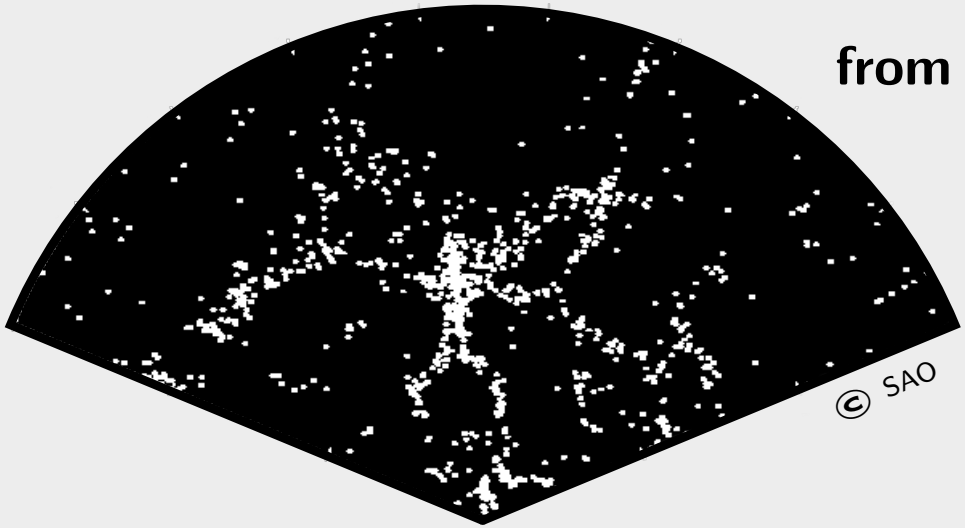
Observatoire astronomique de Strasbourg



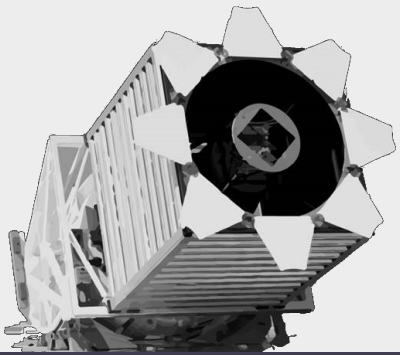
Workshop Action Dark Energy 2022, Marseille, Nov 17 2022

Cosmic web
from observations . . .

de Lapparent et al. 1986

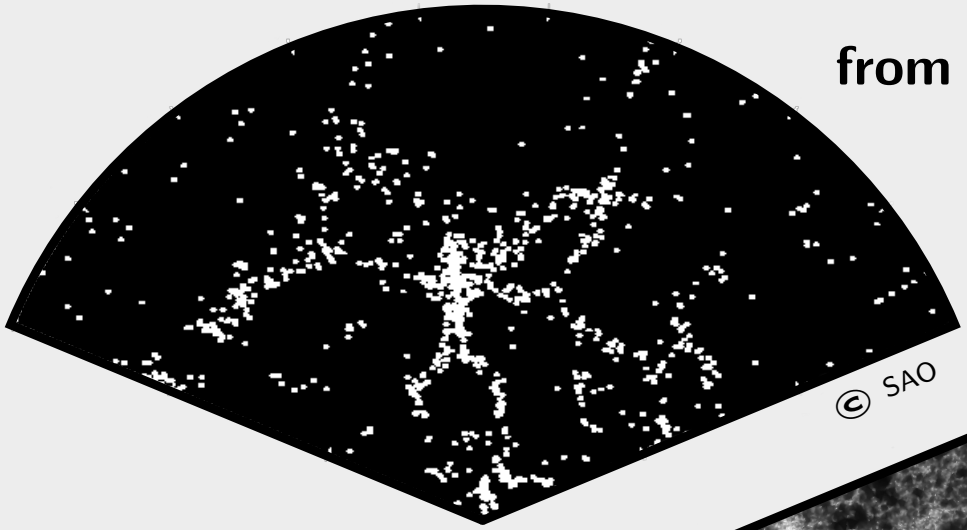


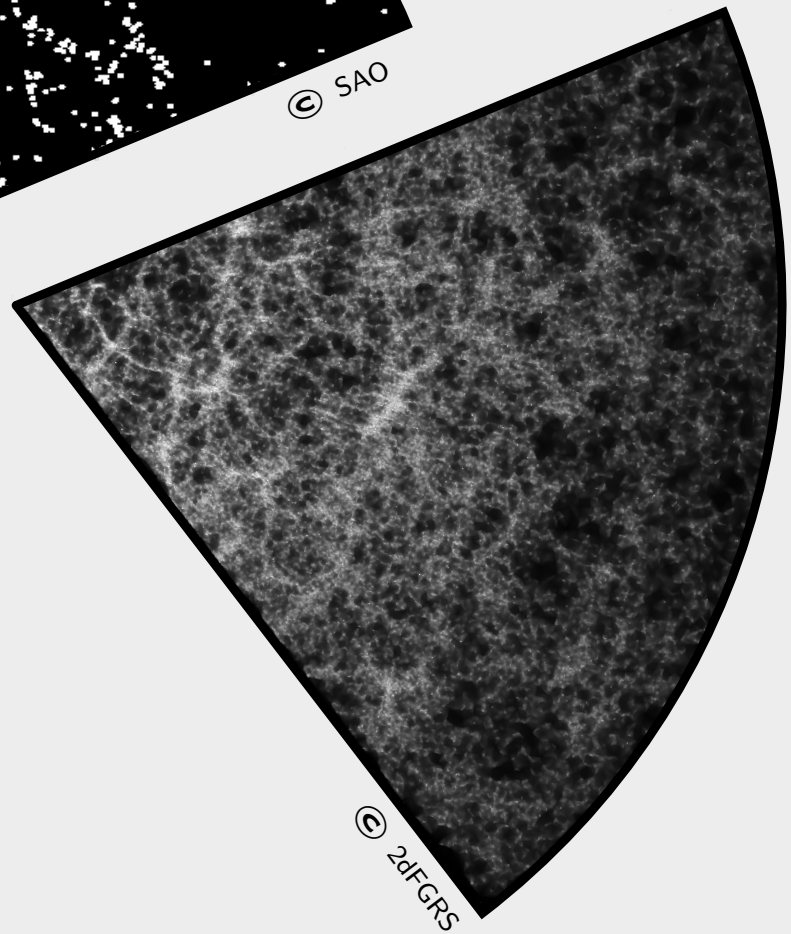
Sloan Foundation Telescope

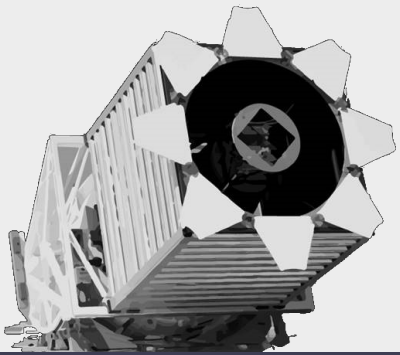


Cosmic web
from observations . . .

de Lapparent et al. 1986
Colless et al. 2003



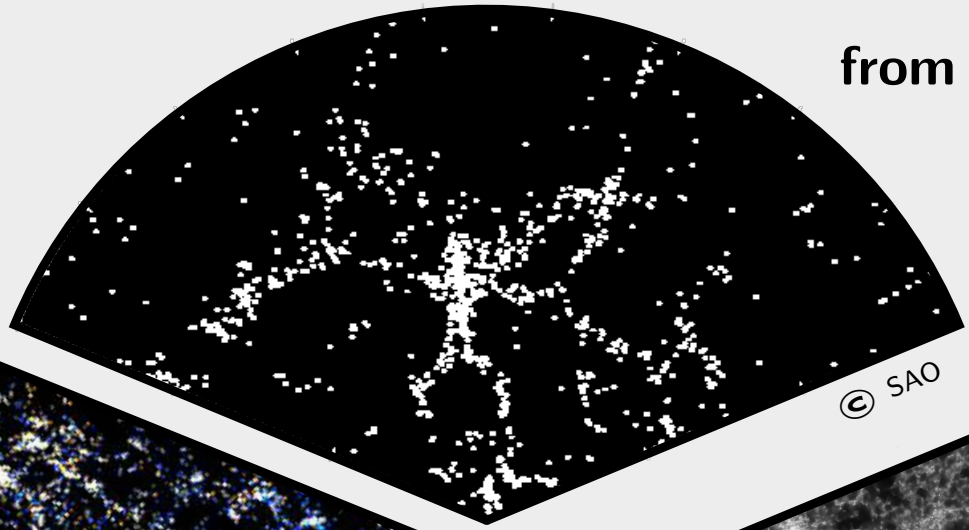


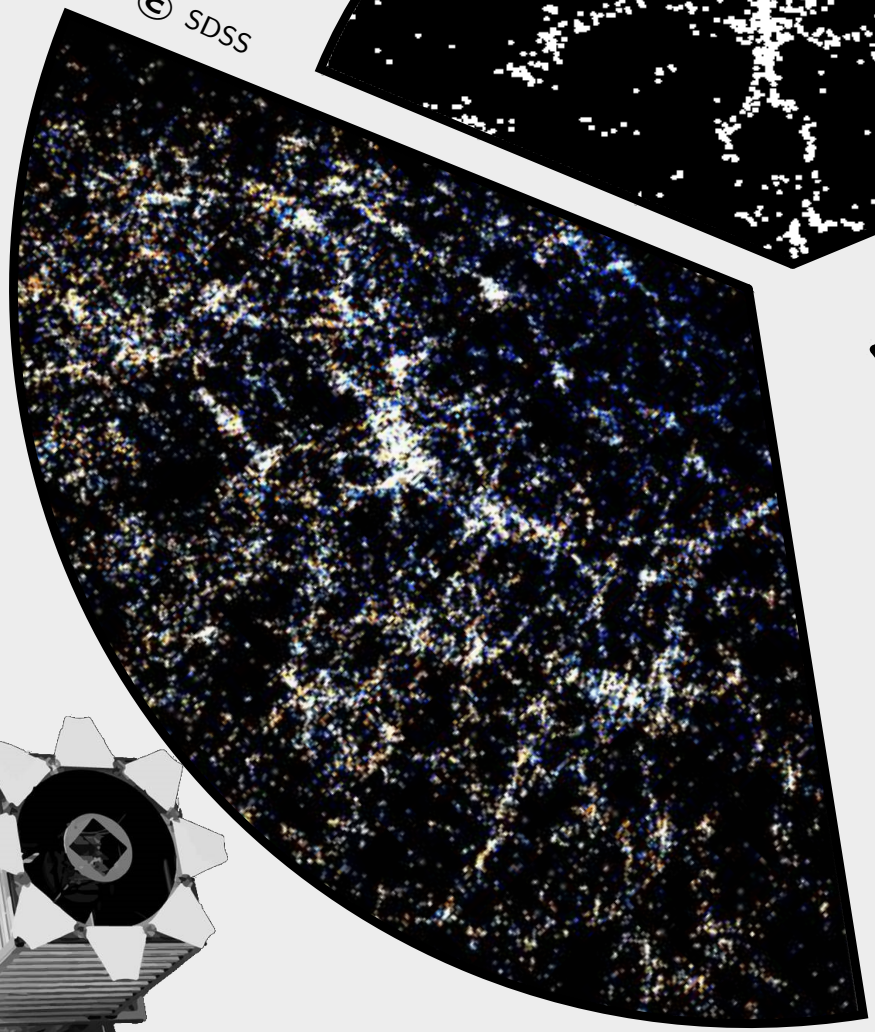


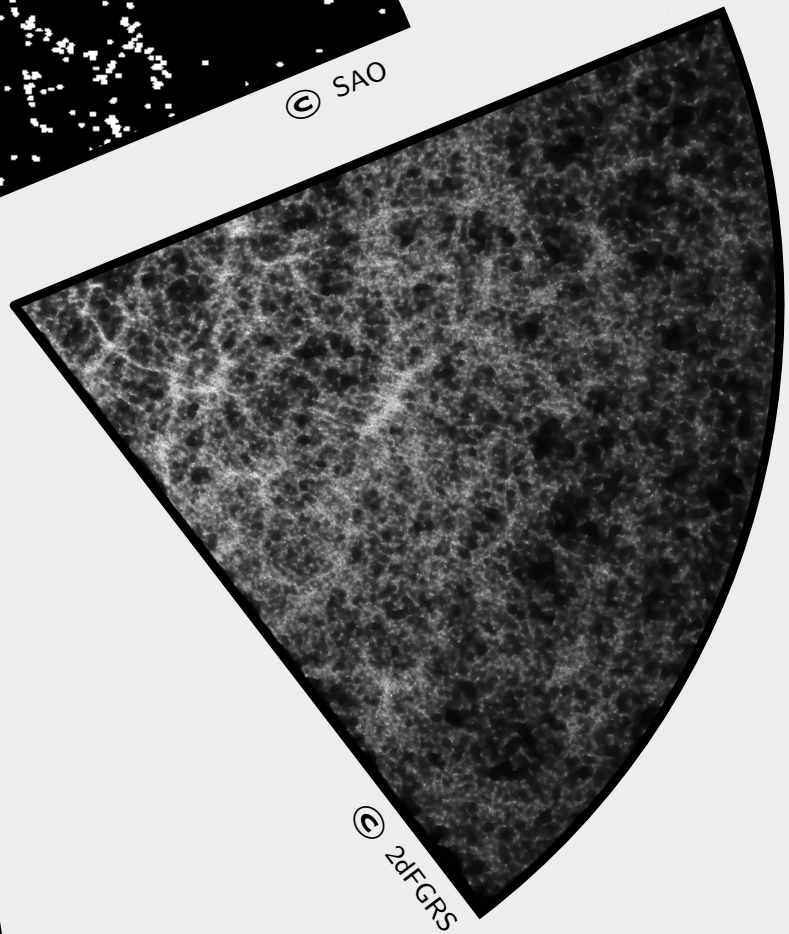
Sloan Foundation Telescope

Cosmic web
from observations . . .

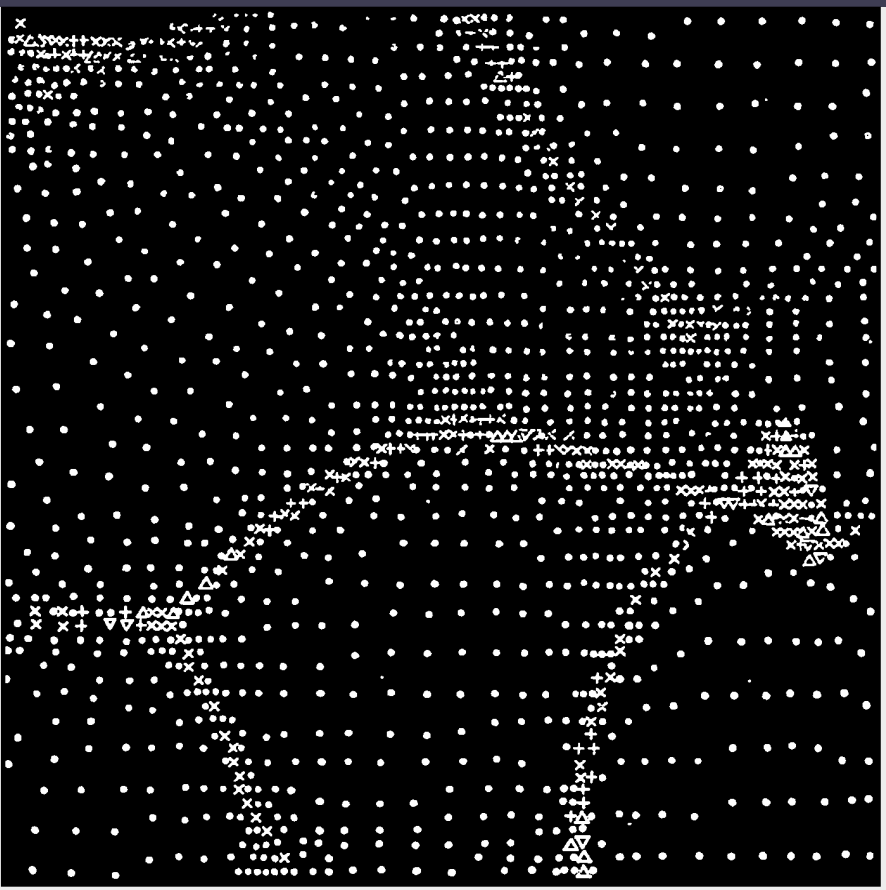
de Lapparent et al. 1986
Colless et al. 2003
Adelman-McCarthy et al. 2008







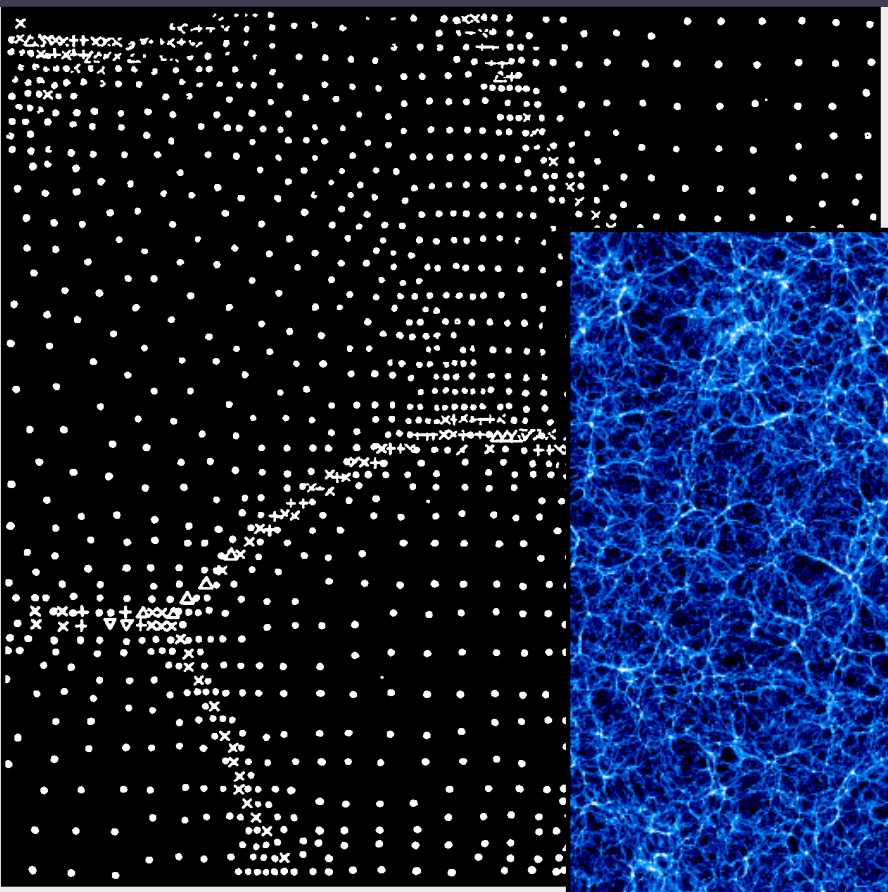
Sloan Foundation Telescope



Sergei Shandarin
Zel'dovich 1970

Cosmic web
. . . to theory

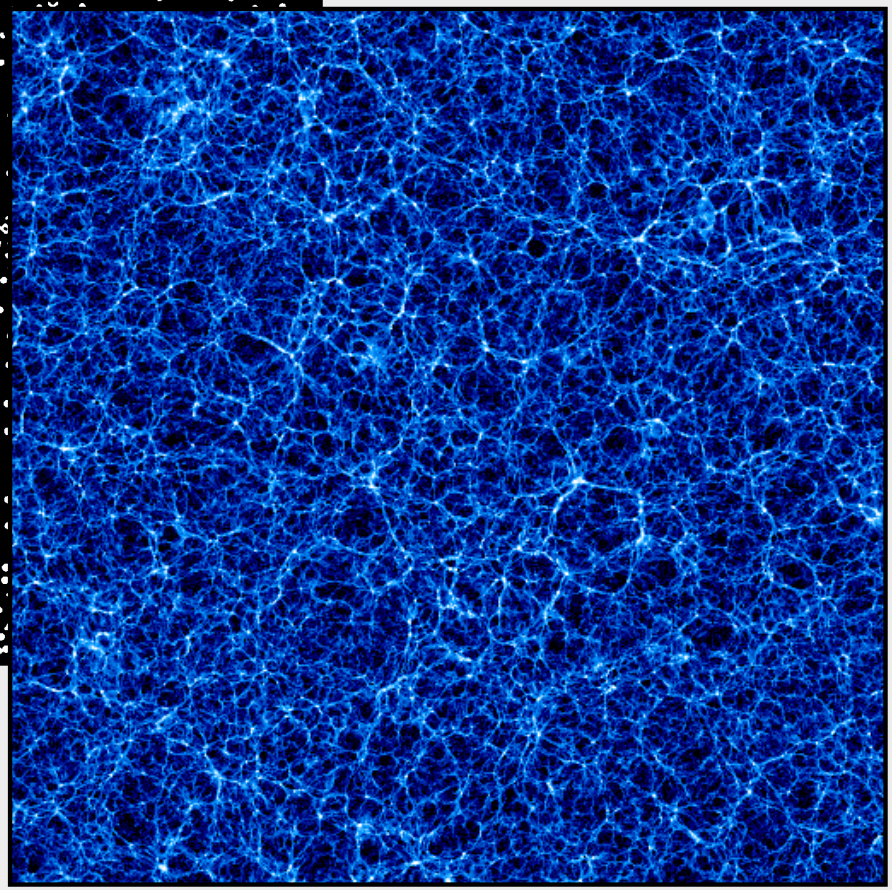
Klypin & Shandarin 1993
Bond, Kofman & Pogosyan 1996



Sergei Shandarin
Zel'dovich 1970

Cosmic web
. . . to theory

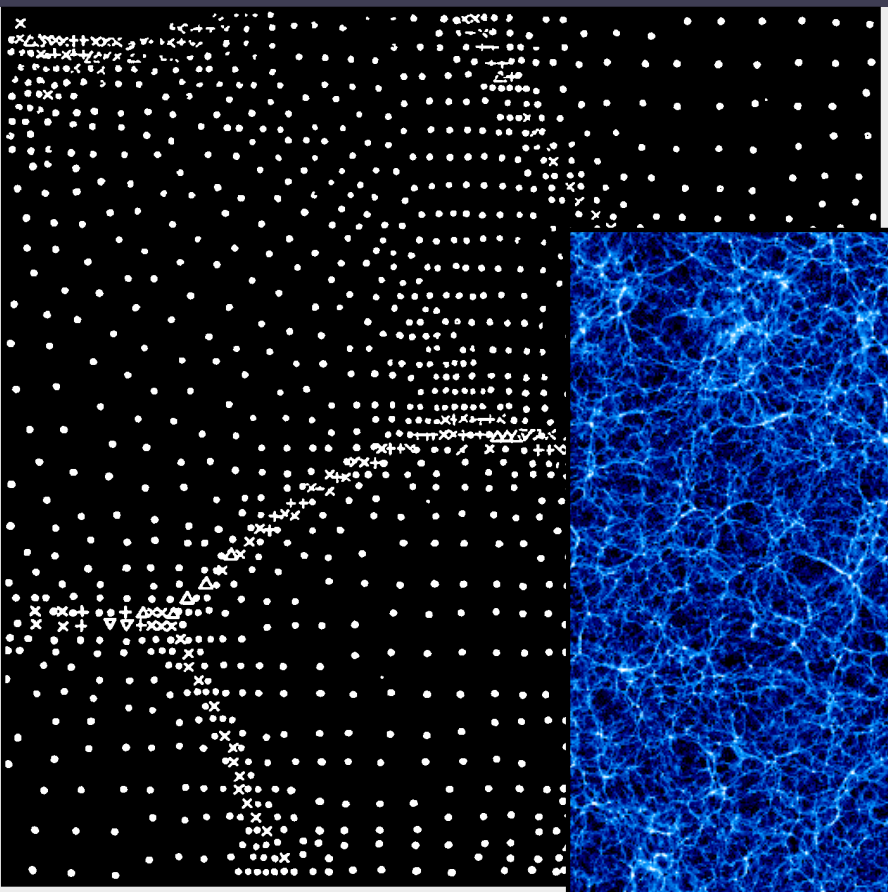
Klypin & Shandarin 1993
Bond, Kofman & Pogosyan 1996



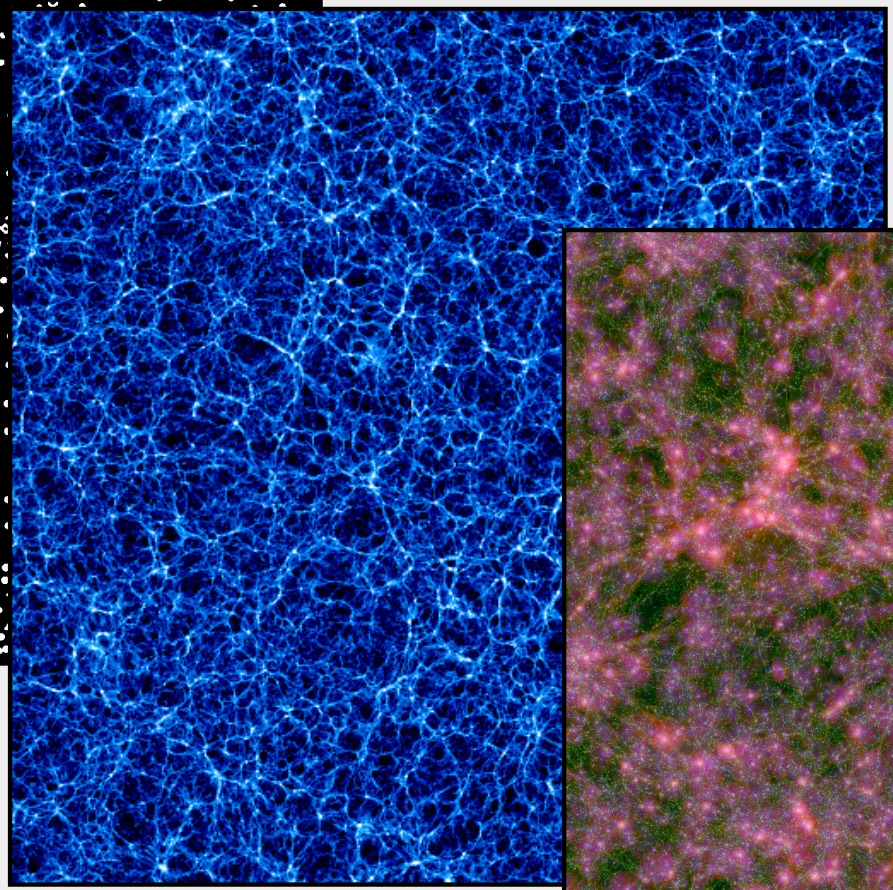
Marenostrum • Yepes et al. 2007

Cosmic web
. . . to theory

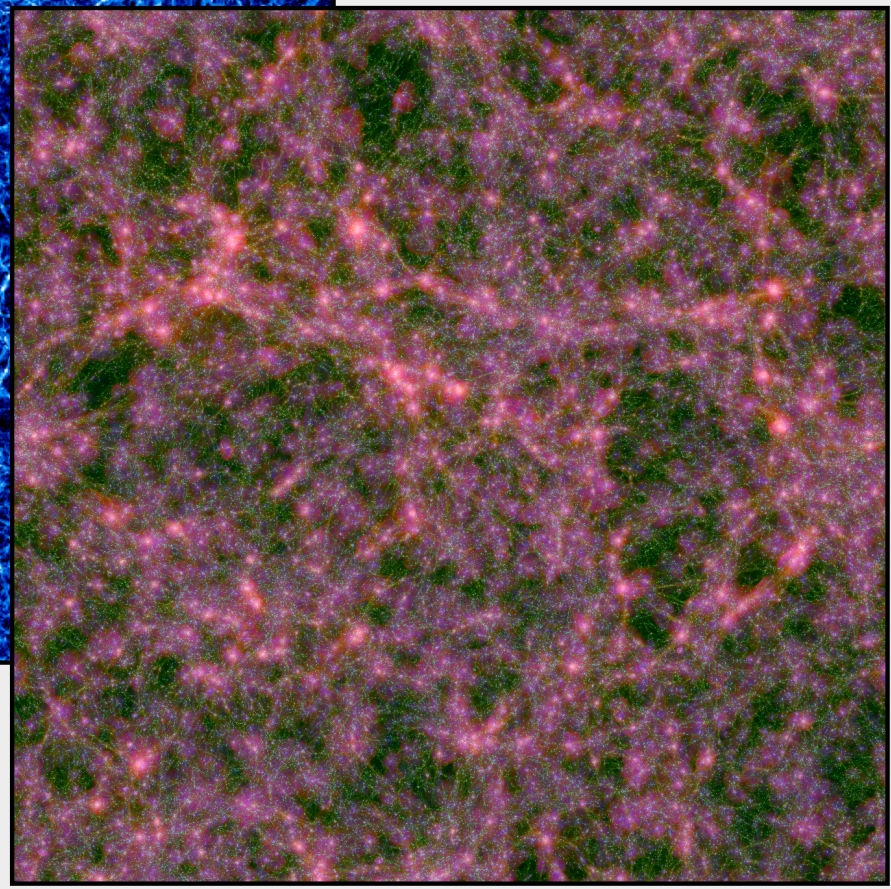
Klypin & Shandarin 1993
Bond, Kofman & Pogosyan 1996



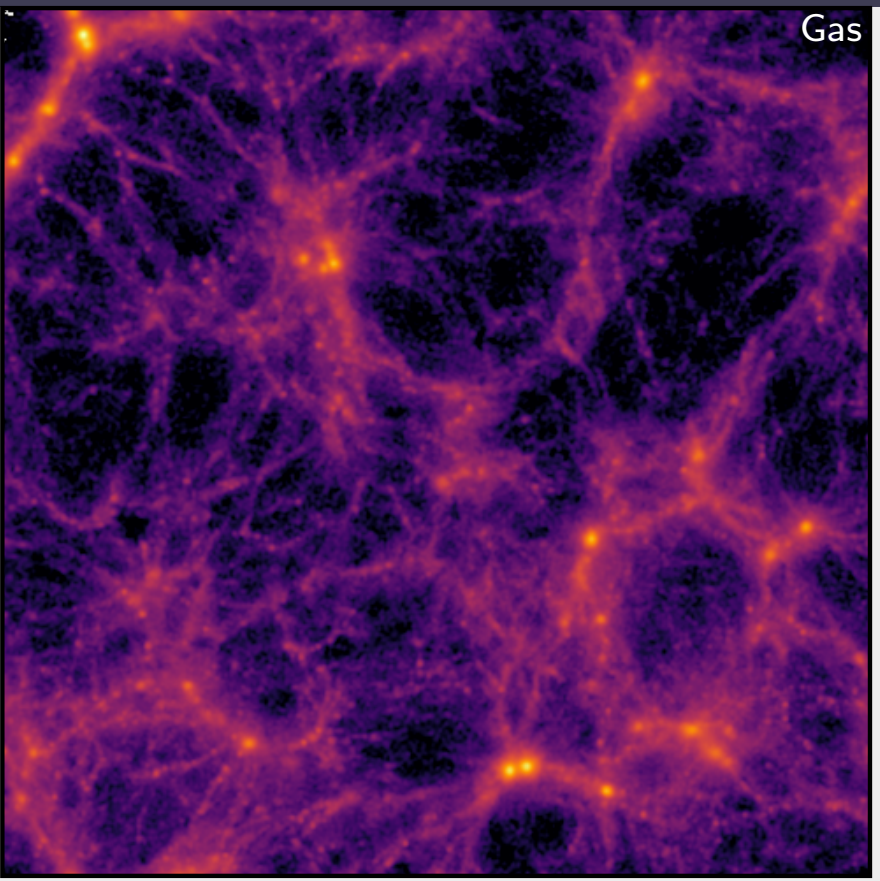
Sergei Shandarin
Zel'dovich 1970



Marenostrum • Yepes et al. 2007



Horizon-AGN • Dubois et al. 2014



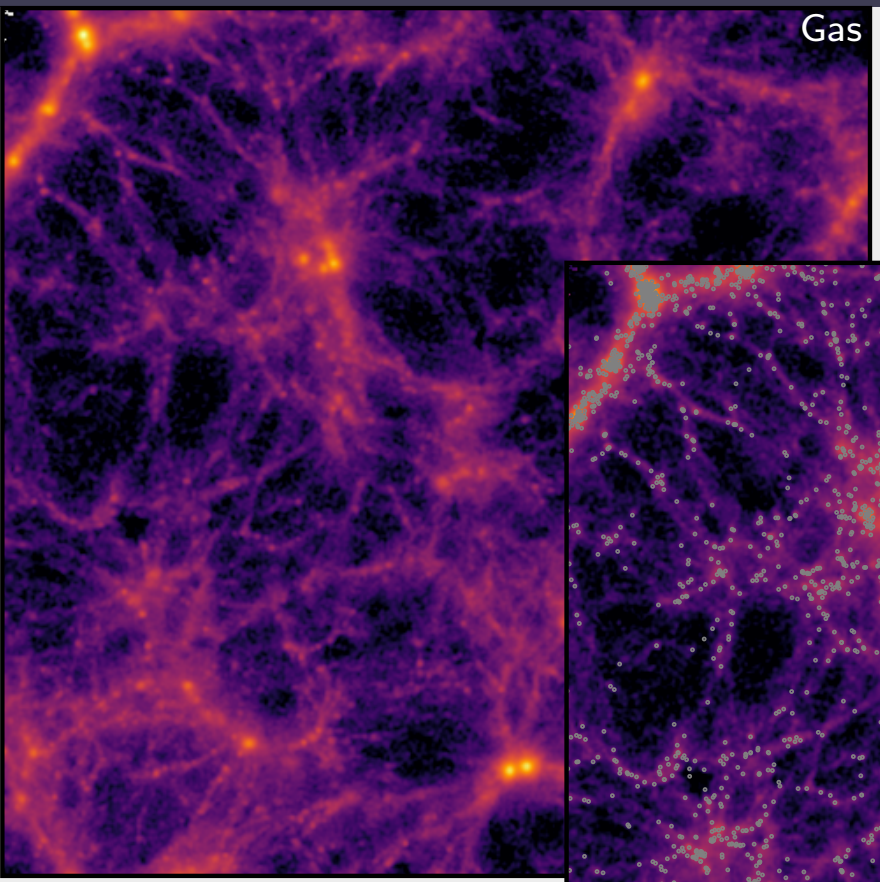
SIMBA • Davé et al. 2019

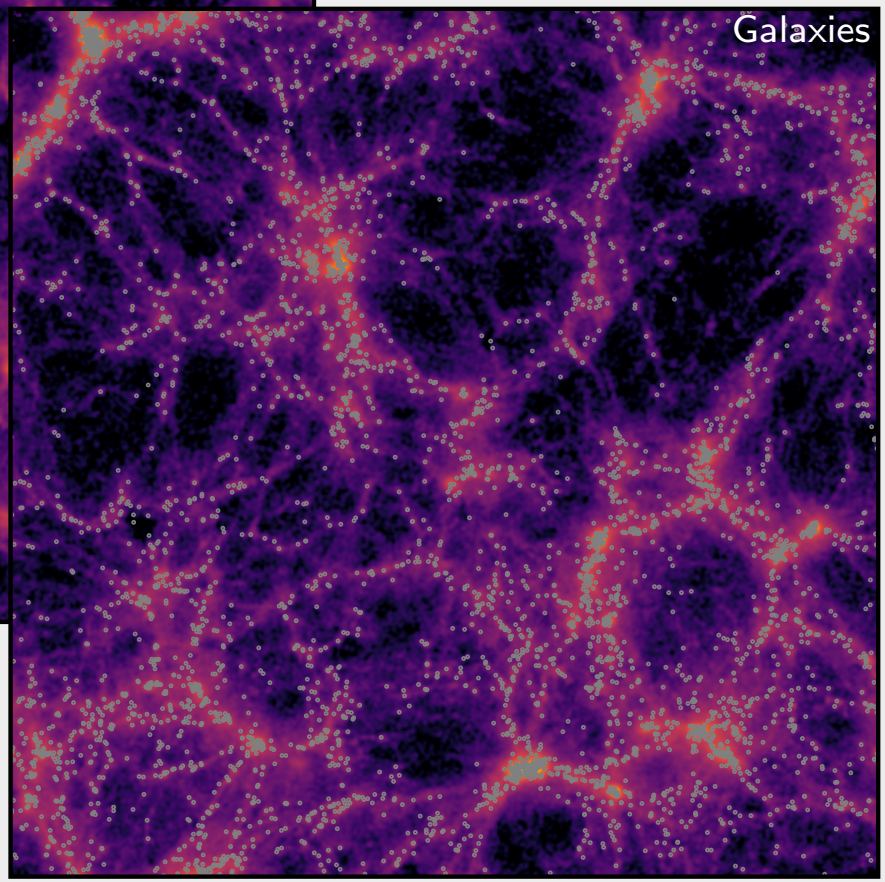
Cosmic connectivity

Codis, Pogosyan & Pichon 2018

Cosmic connectivity

Codis, Pogosyan & Pichon 2018

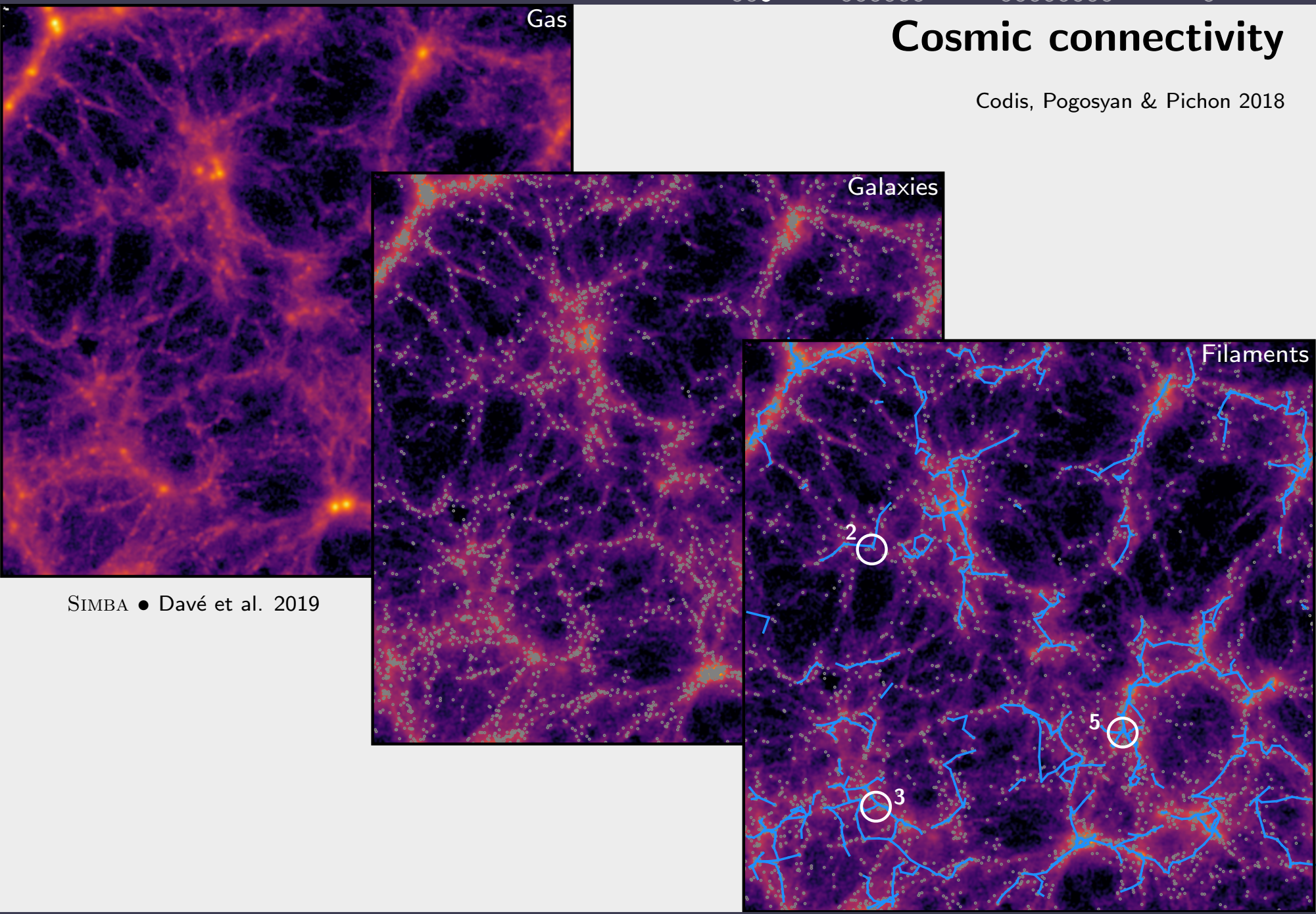




SIMBA • Davé et al. 2019

Cosmic connectivity

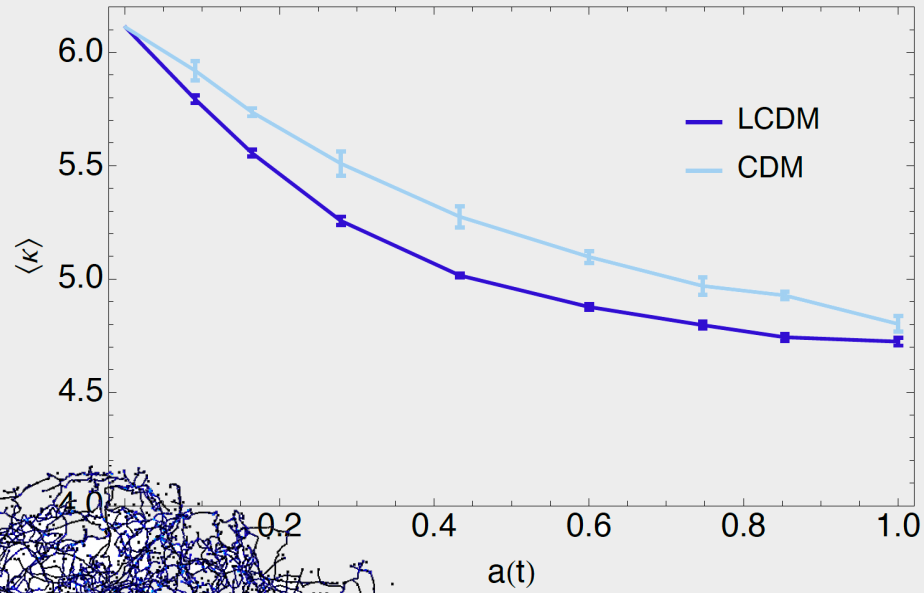
Codis, Pogosyan & Pichon 2018

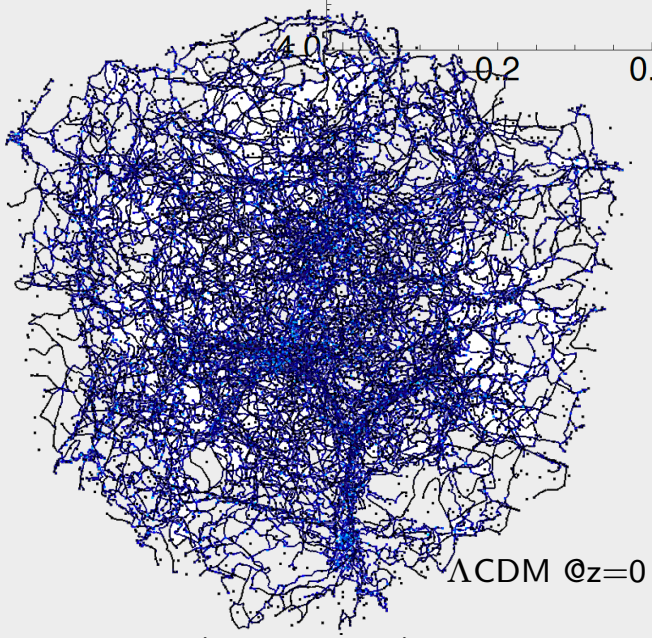


SIMBA • Davé et al. 2019

Connectivity of the 3D dark matter distribution

Redshift evolution of connectivity as a probe of dark energy





ΛCDM @z=0

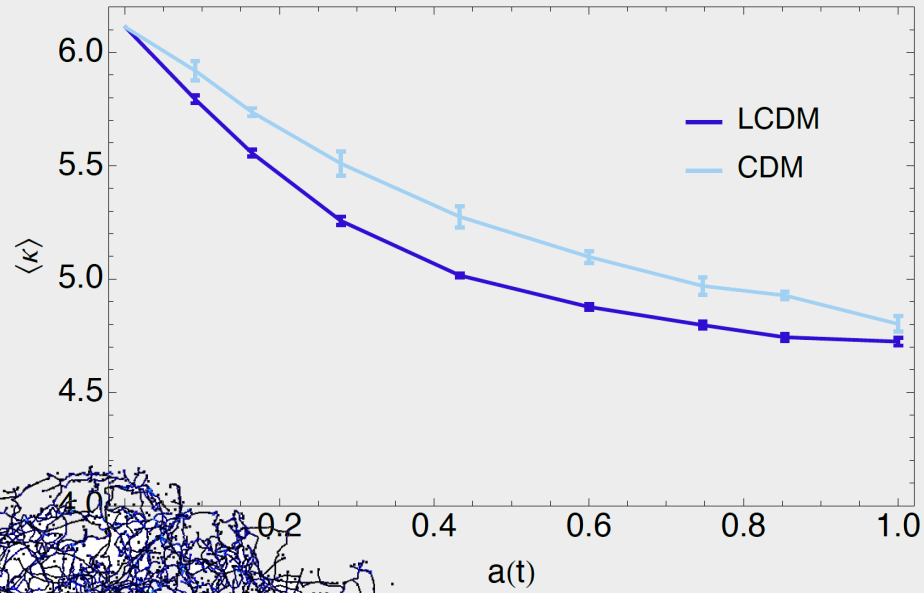
DisPerSE (Sousbie 2011)

18 ΛCDM, 4 CDM simulations:
50 h^{-1} Mpc
256^3 DM particles

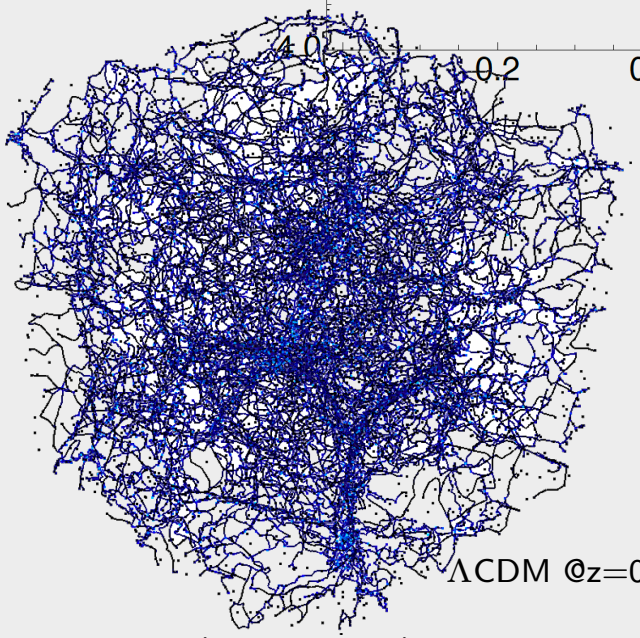
Codis, Pogosyan & Pichon 2018
(see also for GRF connectivity predicted from first principles)

Connectivity of the 3D dark matter distribution

Redshift evolution of connectivity as a probe of dark energy



18 ΛCDM, 4 CDM simulations:
50 h^{-1} Mpc
256^3 DM particles



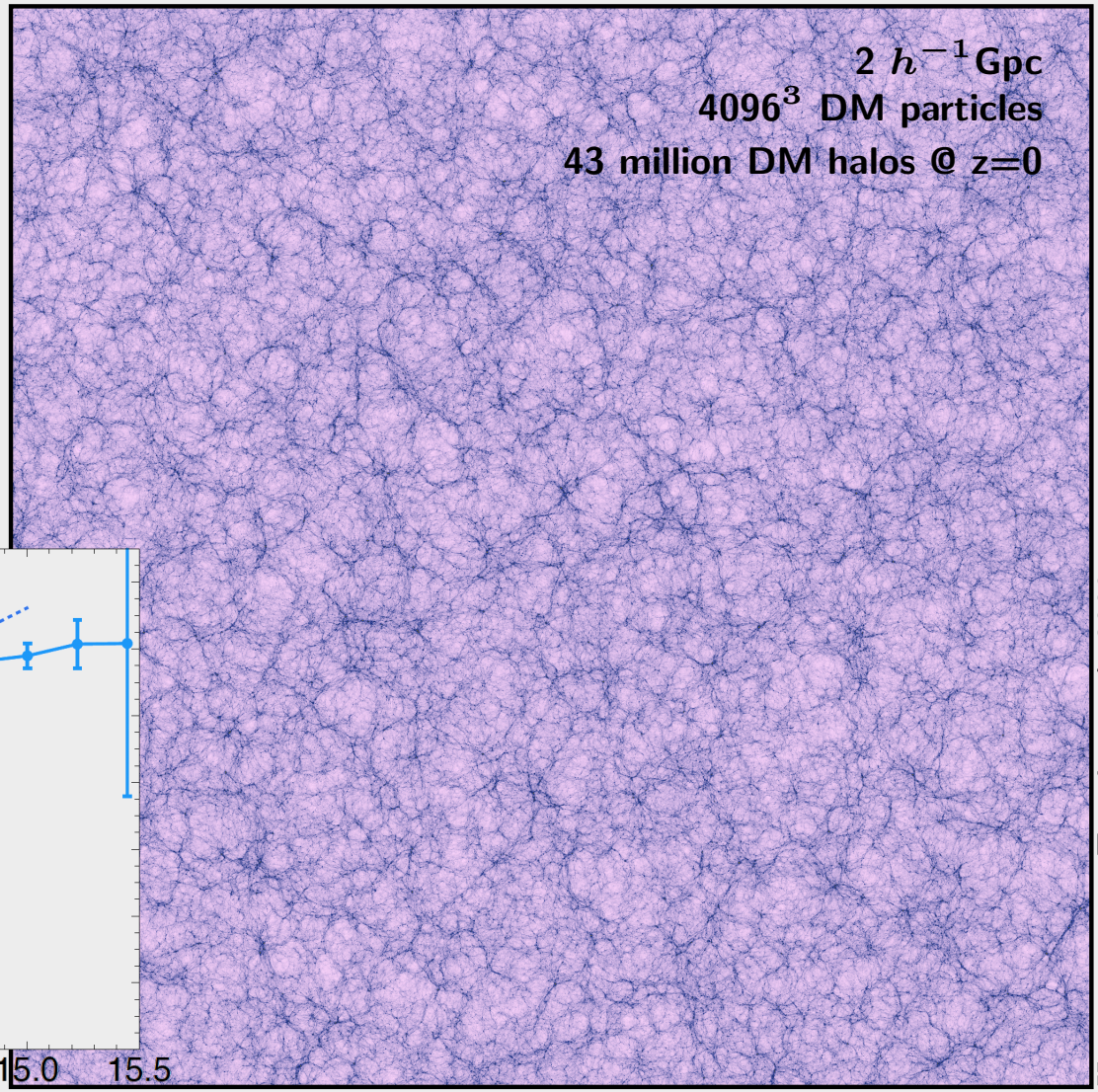
ΛCDM @z=0

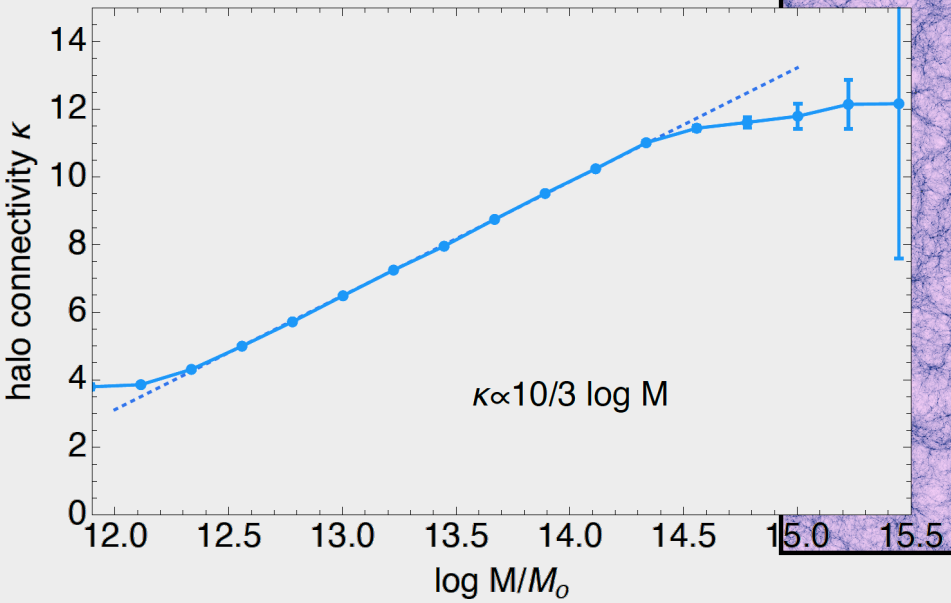
DisPerSE (Sousbie 2011)

- connectivity decreases with time
- dark energy (Λ) changes the overall shape

Codis, Pogosyan & Pichon 2018
(see also for GRF connectivity predicted from first principles)

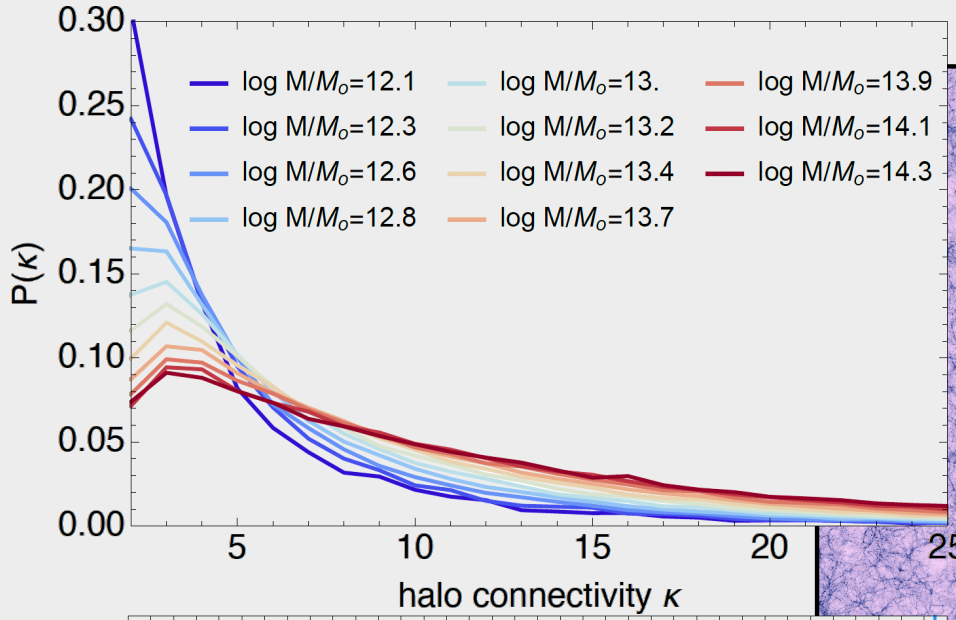
Connectivity of dark matter halos

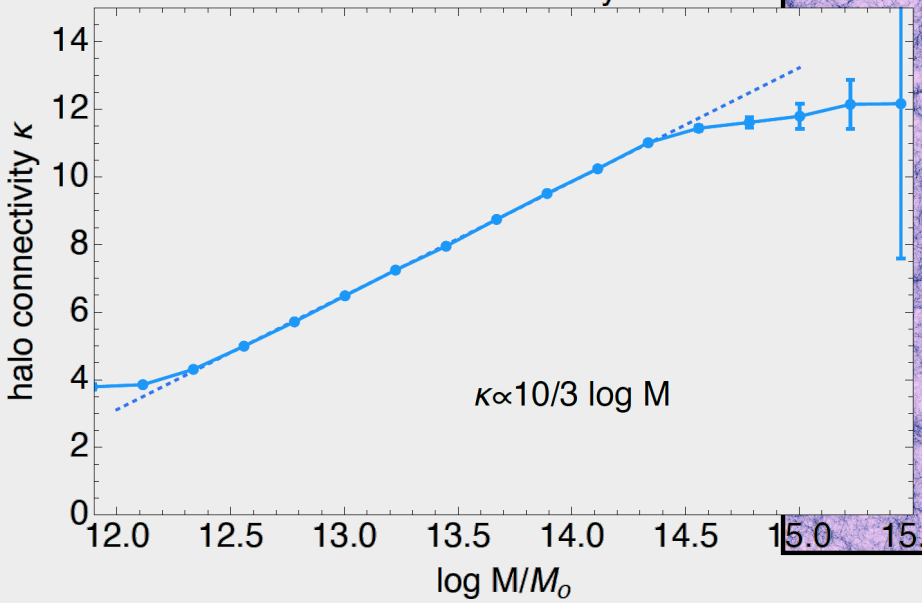


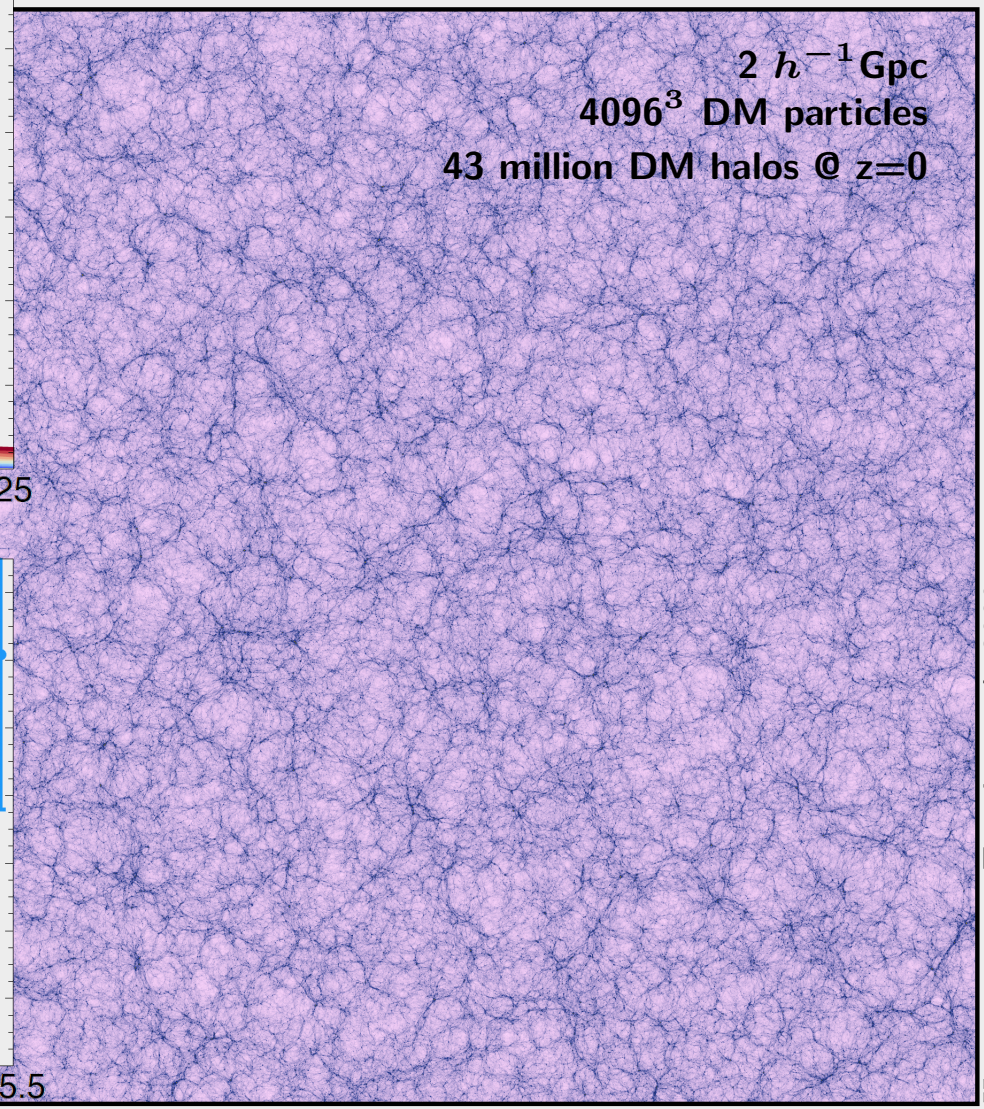


Codis, Pogosyan & Pichon 2018

Connectivity of dark matter halos

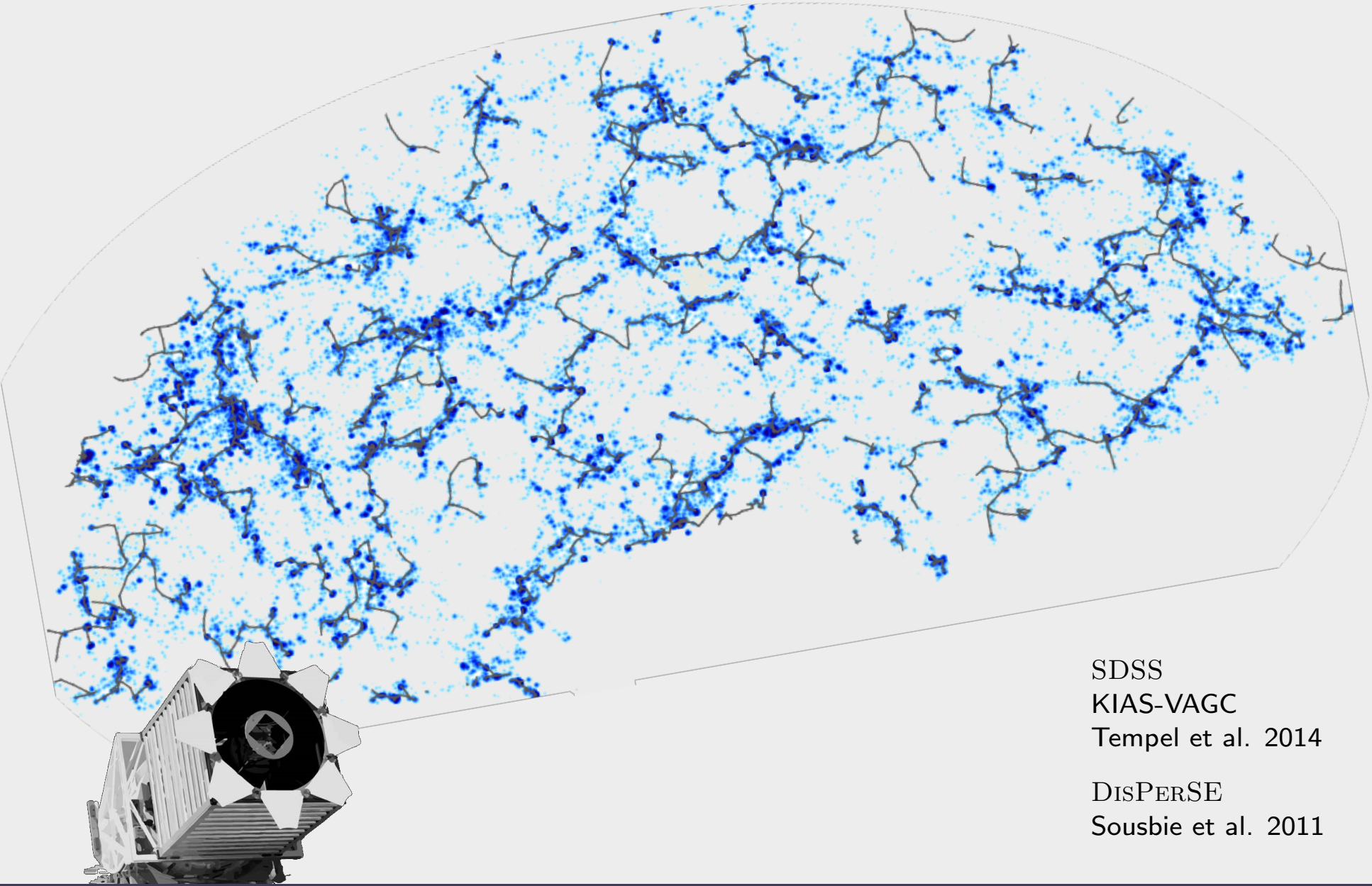






Codis, Pogosyan & Pichon 2018

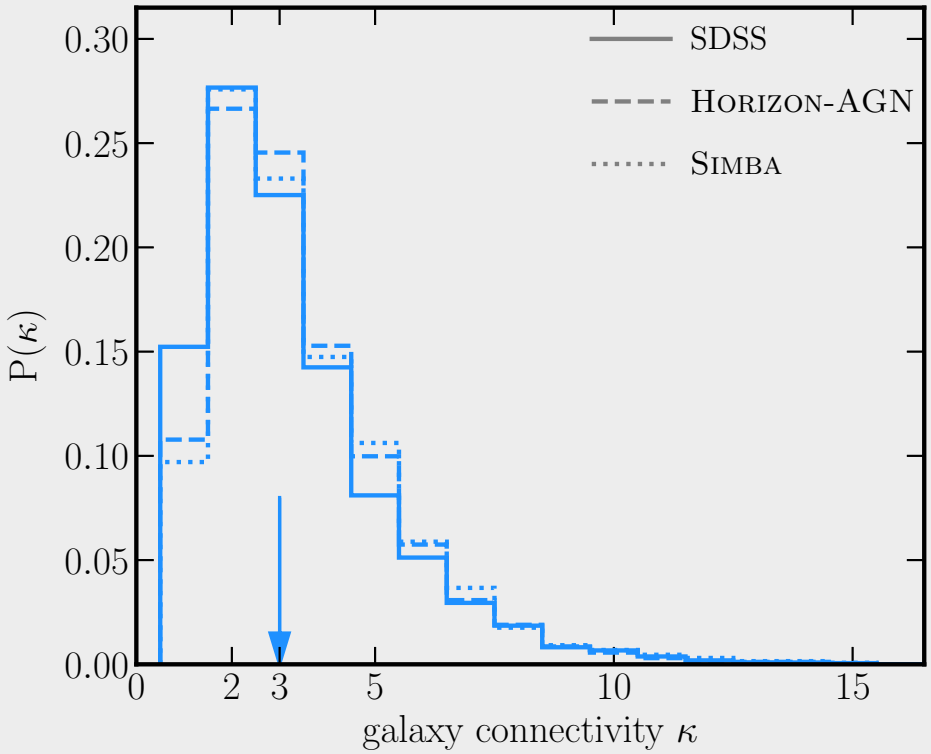
Connectivity of galaxies



SDSS
KIAS-VAGC
Tempel et al. 2014

DisPerSE
Sousbie et al. 2011

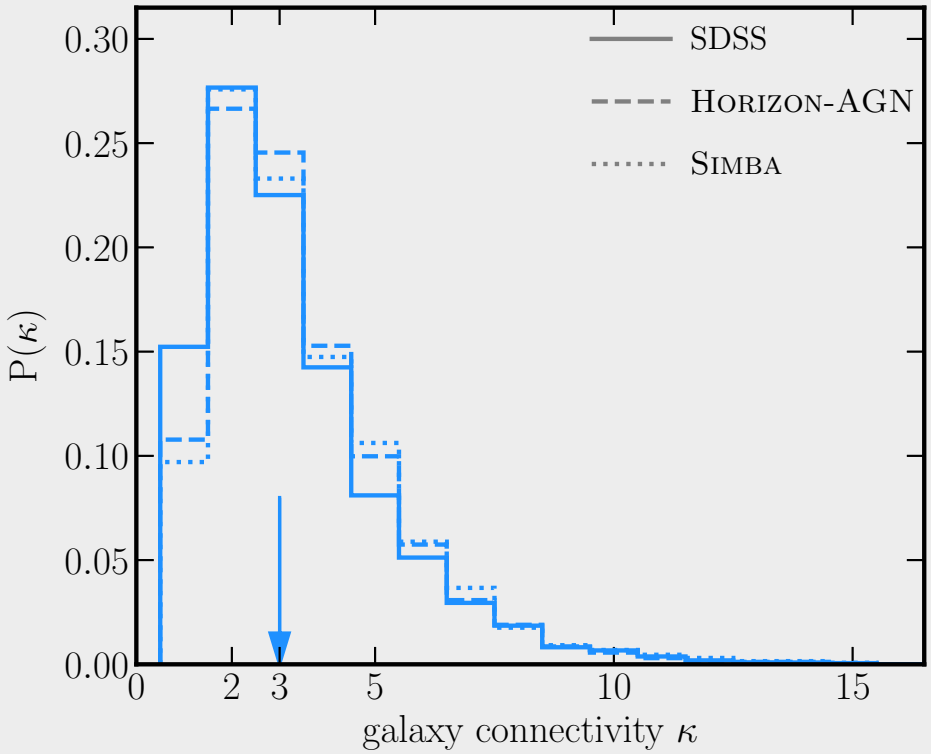
Connectivity of galaxies

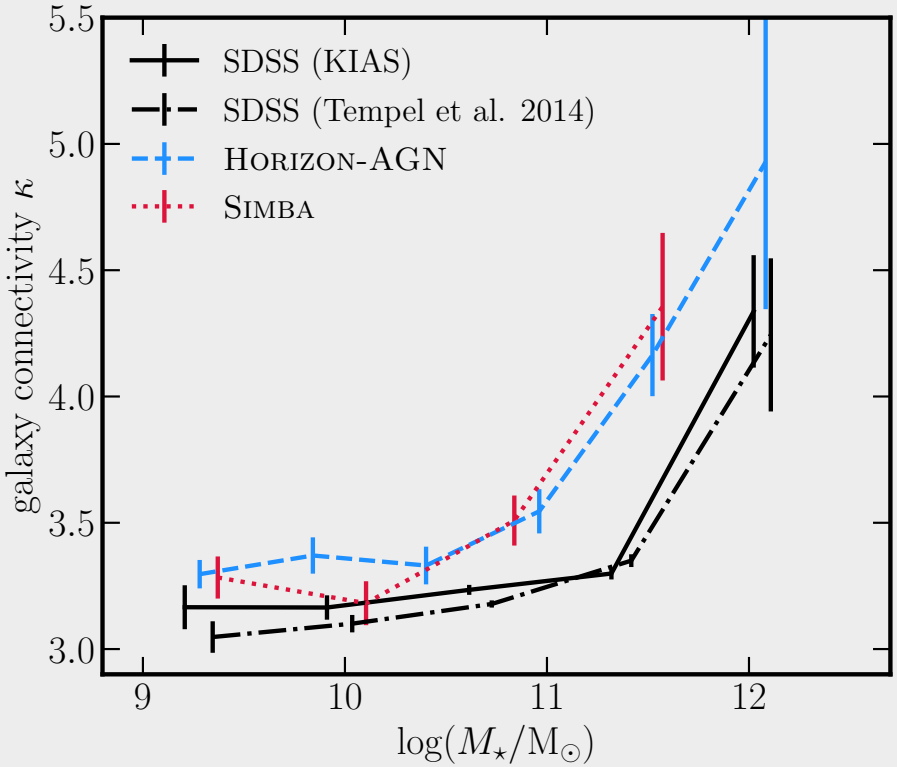


Kraljic et al. 2020b

see also Darragh-Ford et al. 2019 for BCGs

Connectivity of galaxies

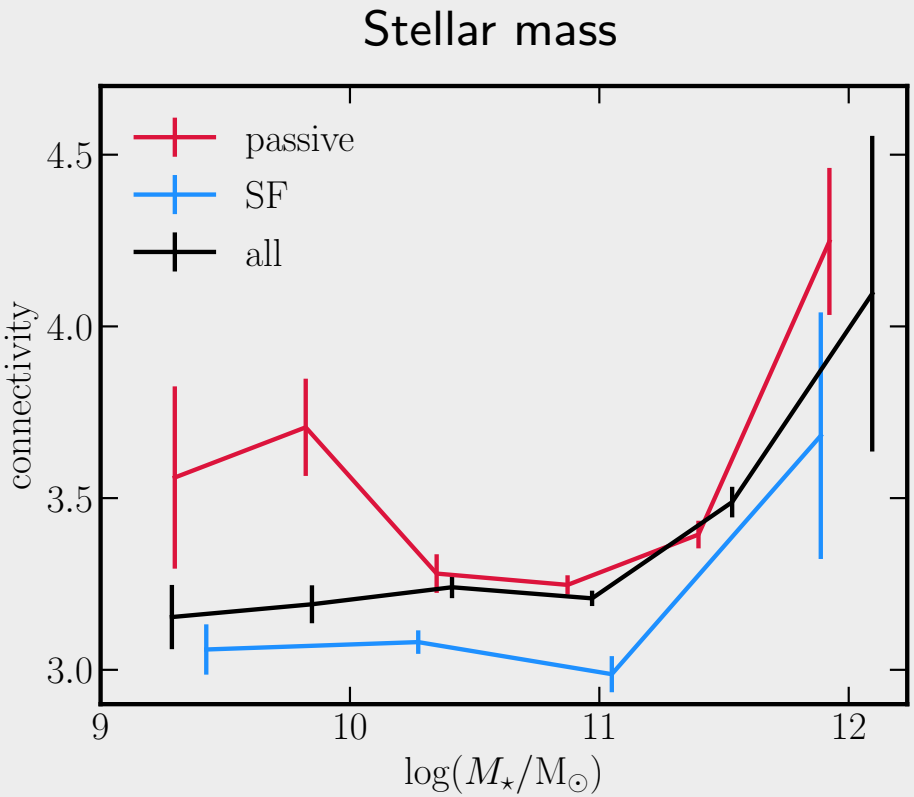


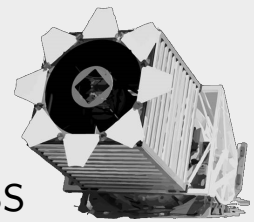


Kraljic et al. 2020b

see also Darragh-Ford et al. 2019 for BCGs

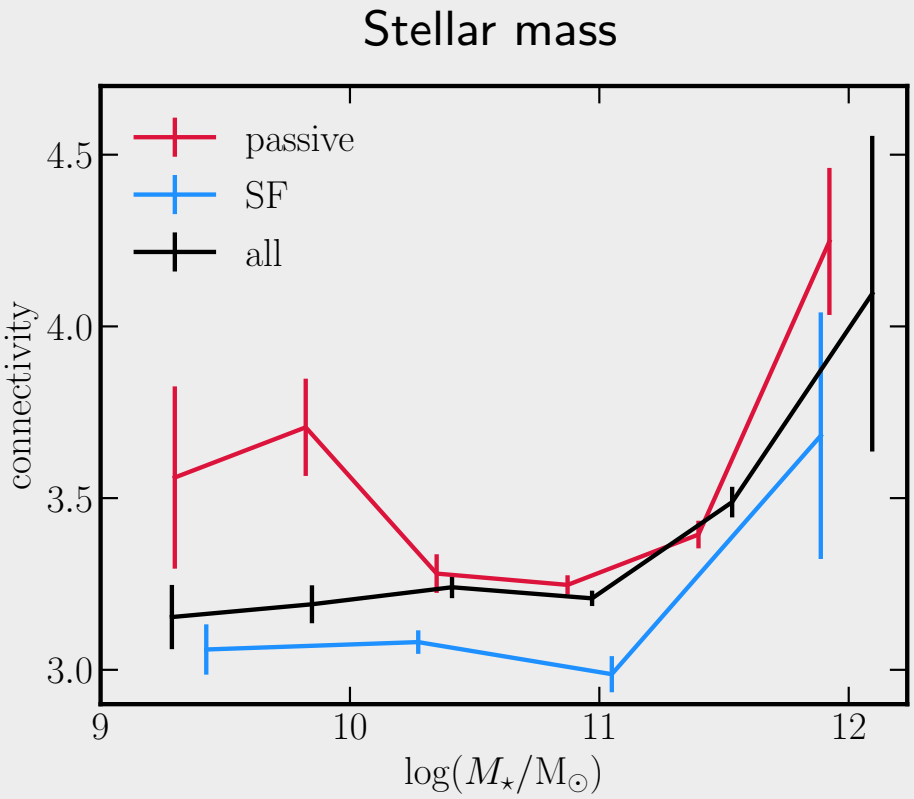
Connectivity of galaxies

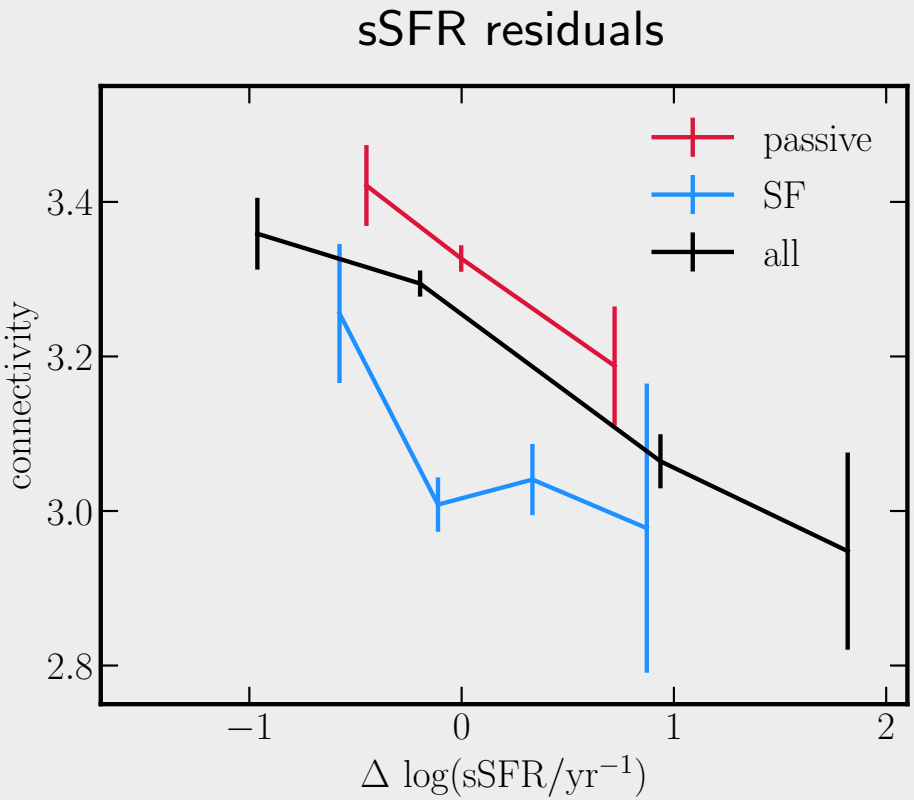



SDSS

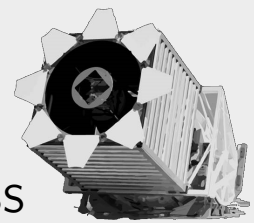
Kraljic et al. 2020b

Connectivity of galaxies



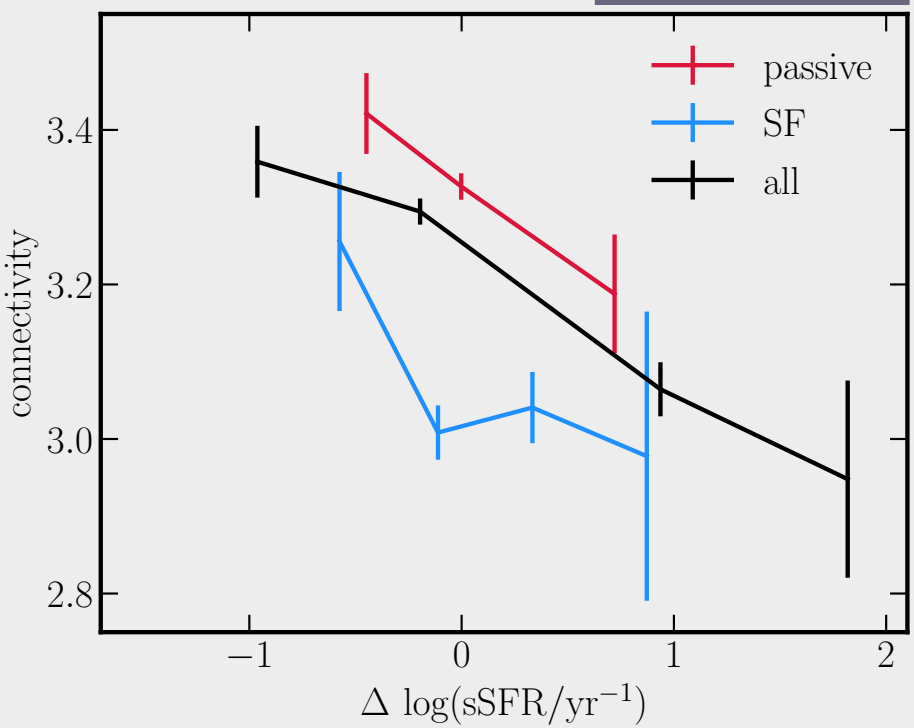


Kraljic et al. 2020b

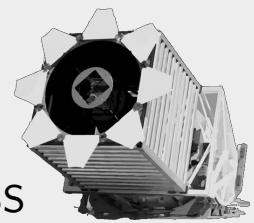

SDSS

Connectivity of galaxies

Star formation

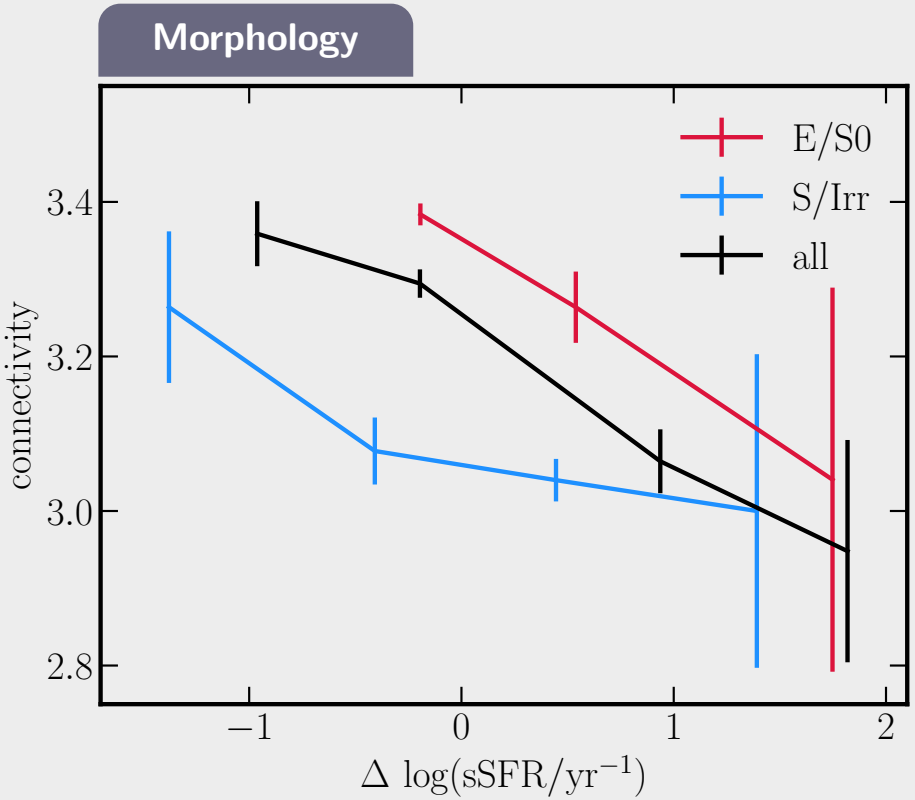


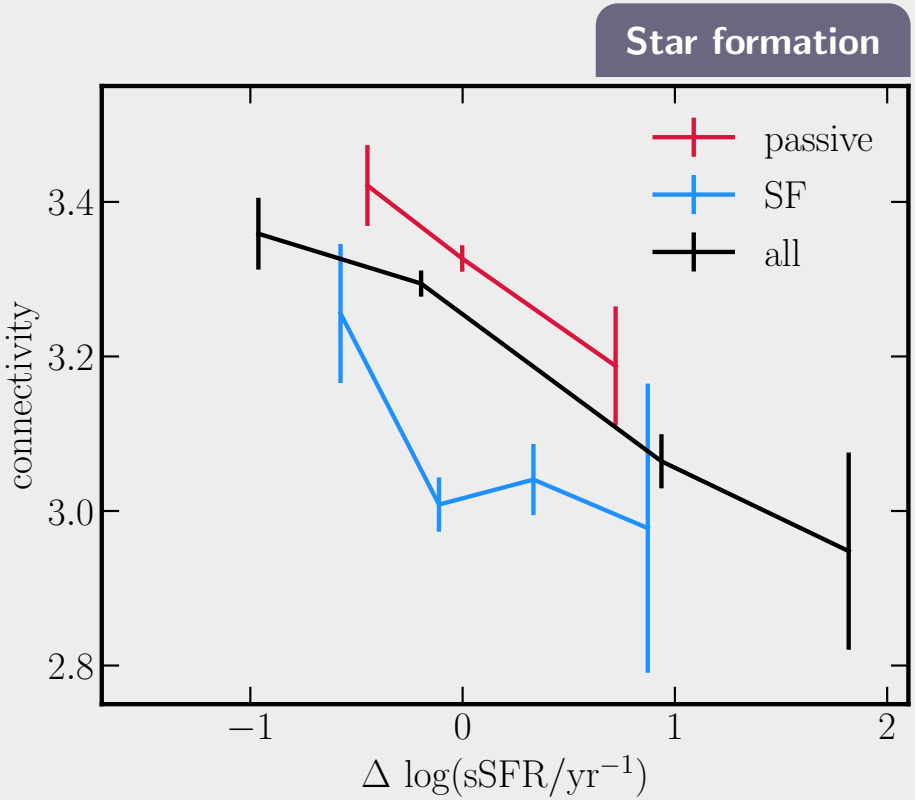
Kraljic et al. 2020b



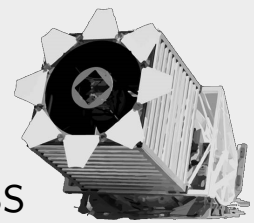
SDSS

Connectivity of galaxies



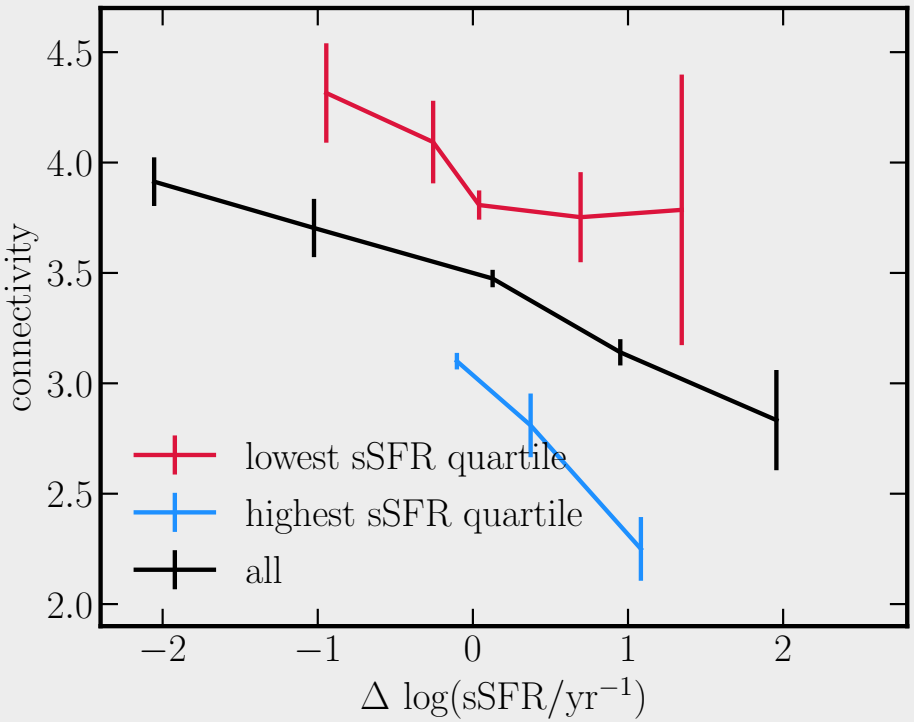


Kraljic et al. 2020b

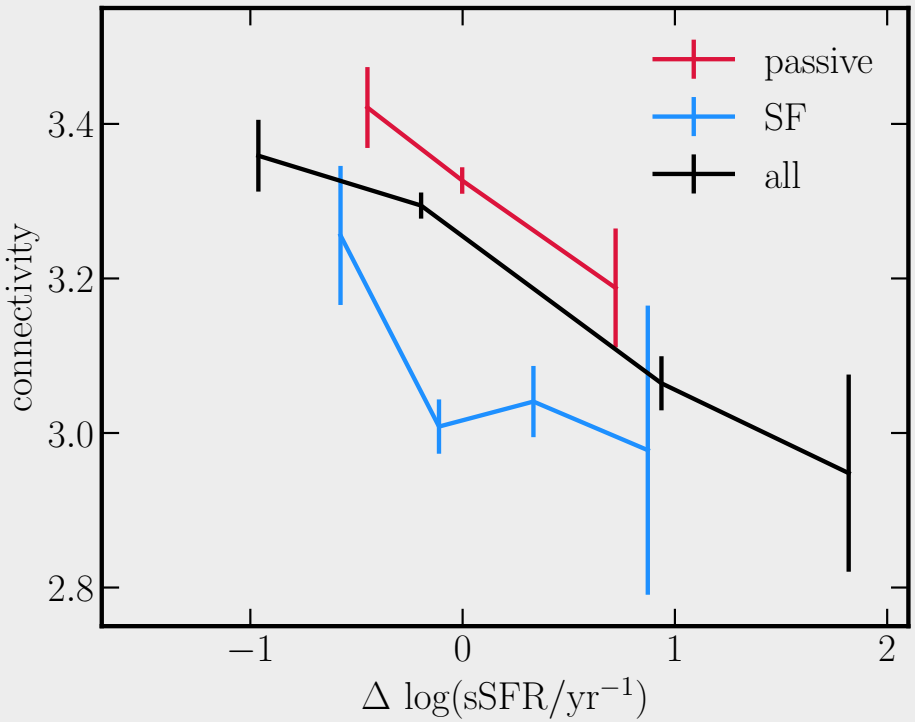


SDSS

Connectivity of galaxies

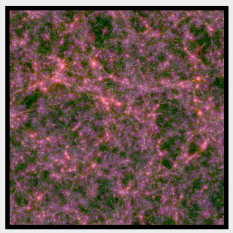


Star formation

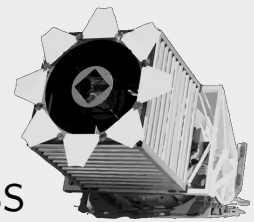


Kraljic et al. 2020b

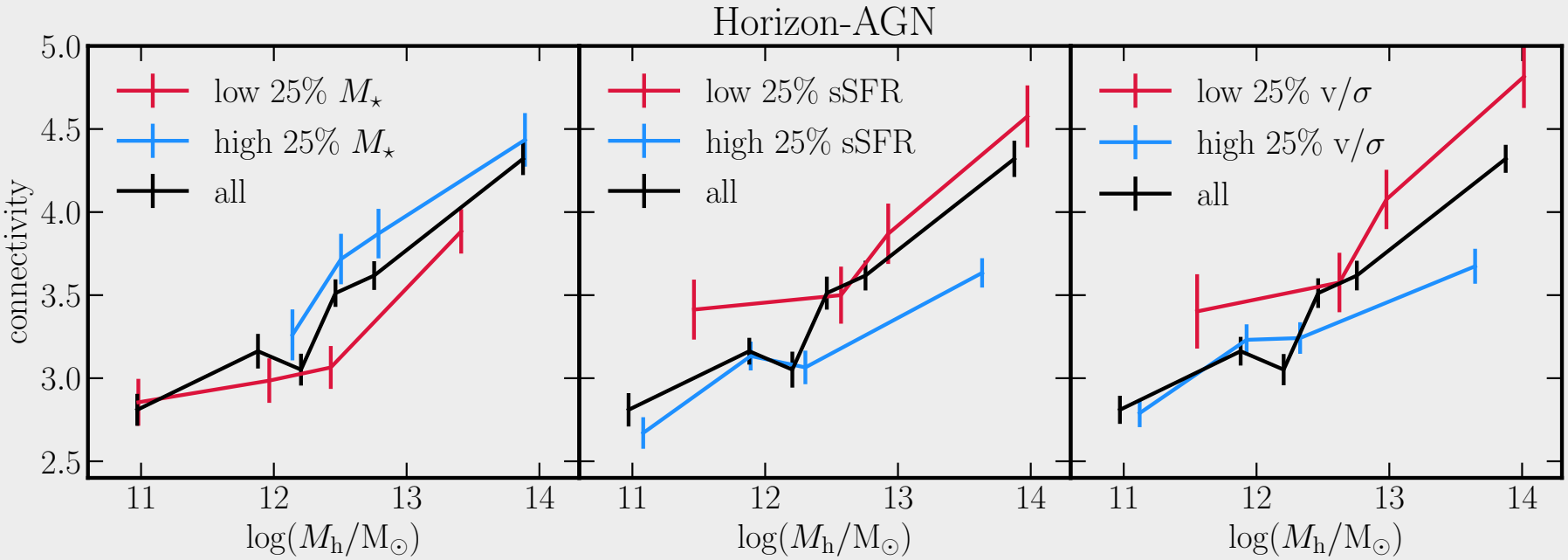
Horizon-AGN
(also Simba)



SDSS



Connectivity of galaxies' halos

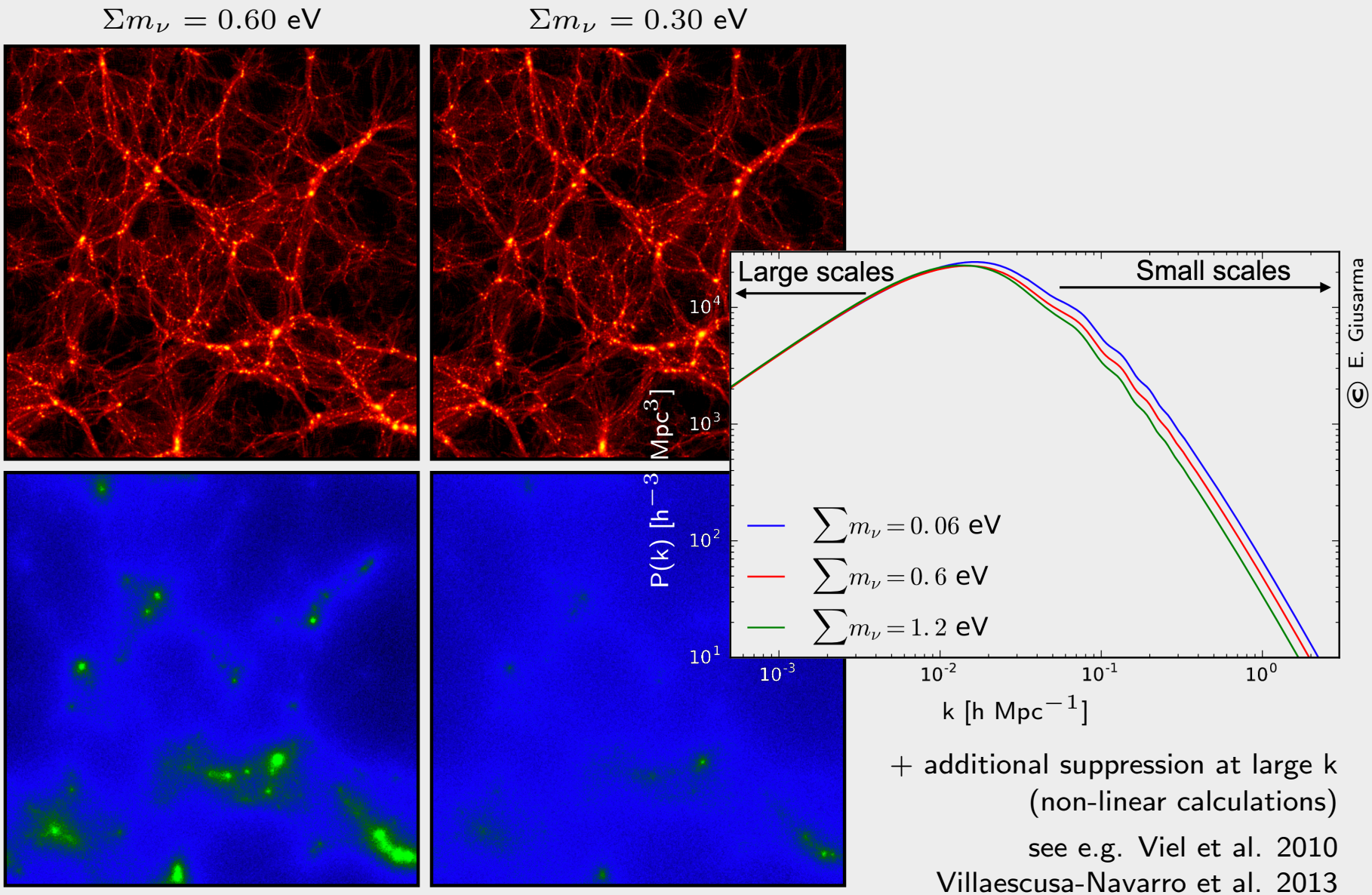


At fixed halo mass, galaxies with higher connectivity tend to have

- higher mass
- lower sSFR
- more ellipsoidal morphology

Kraljic et al. 2020b

Massive neutrinos

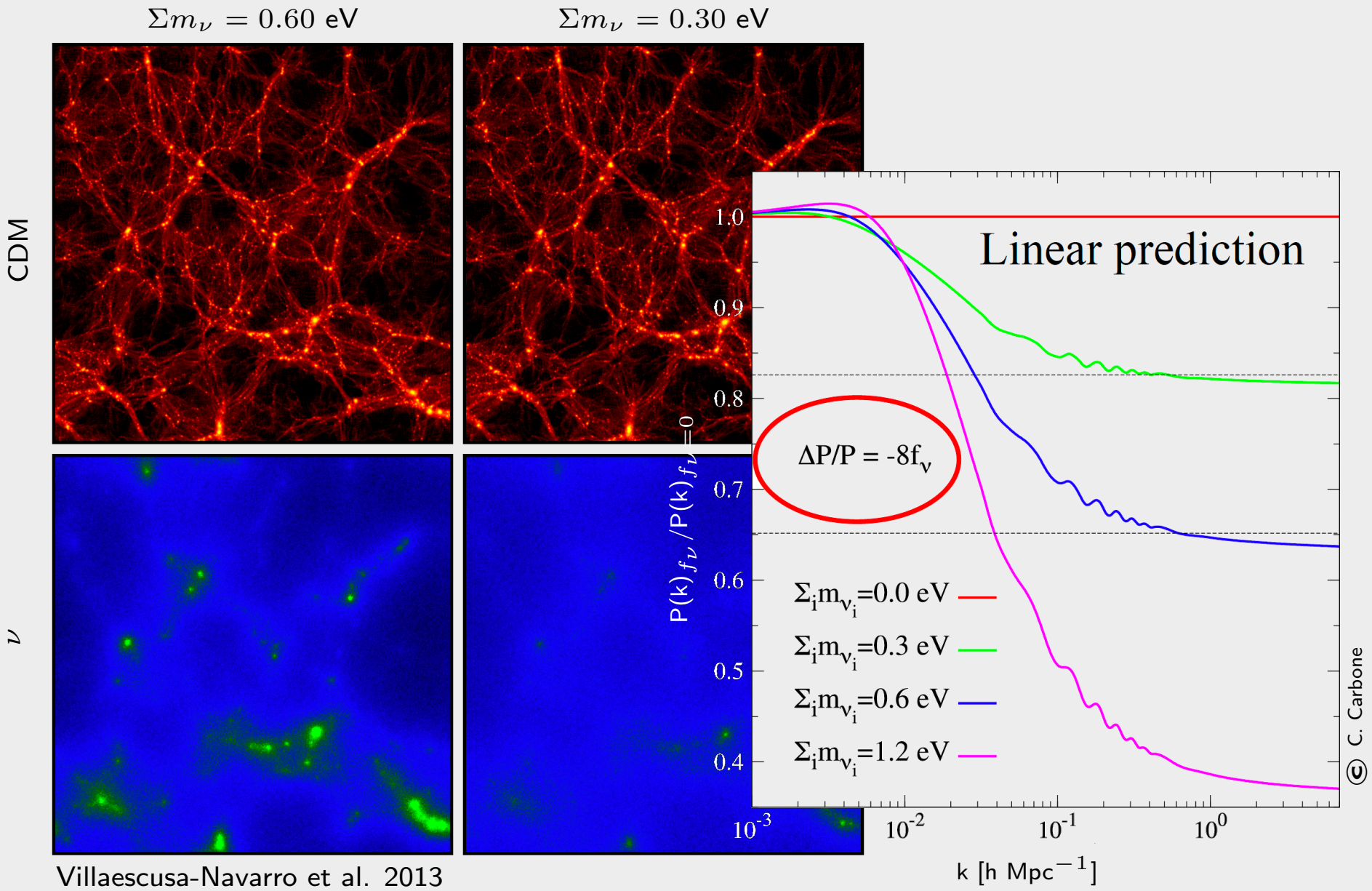


Villaescusa-Navarro et al. 2013

+ additional suppression at large k (non-linear calculations)

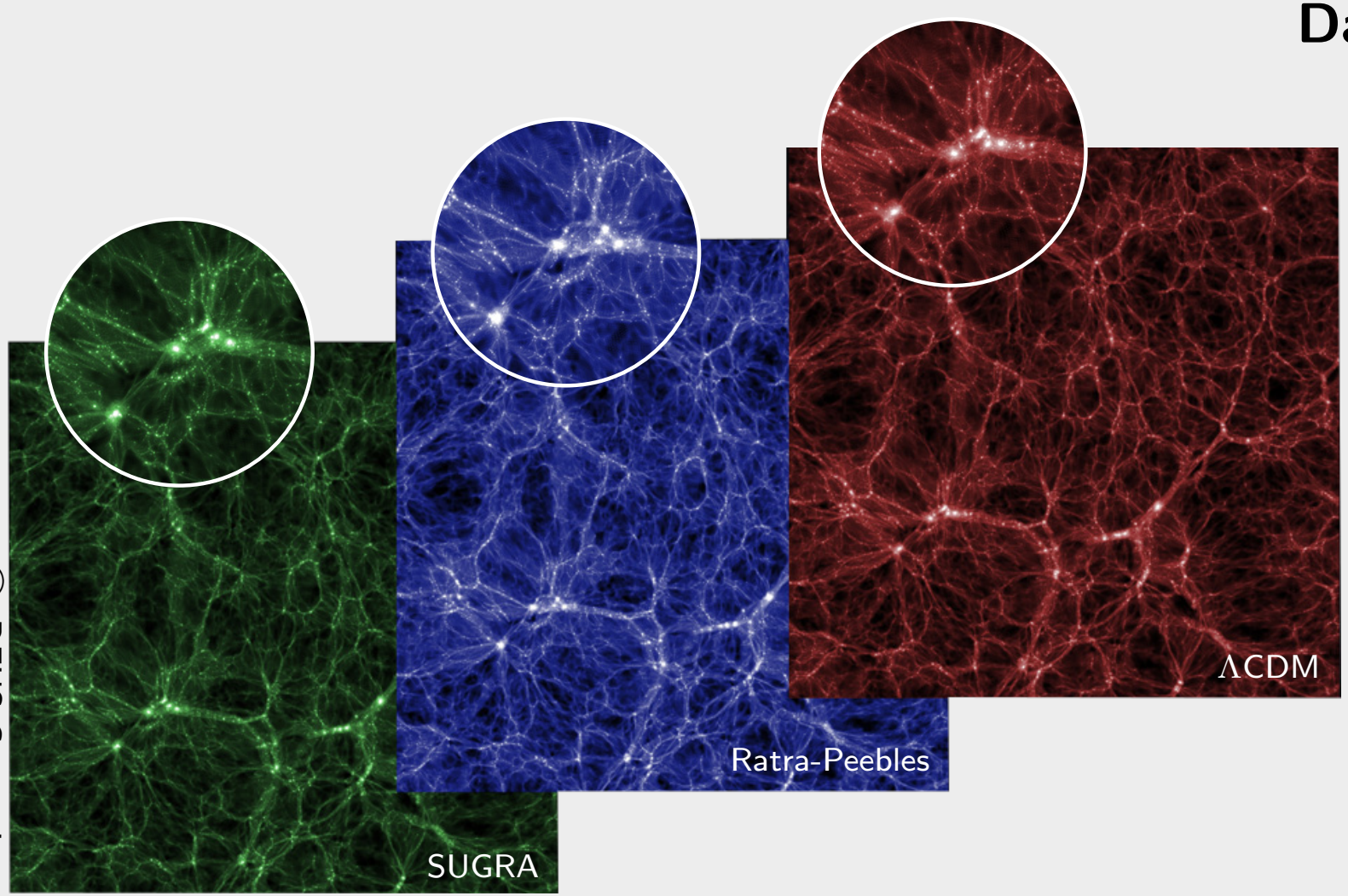
see e.g. Viel et al. 2010
Villaescusa-Navarro et al. 2013

Massive neutrinos



Villaescusa-Navarro et al. 2013

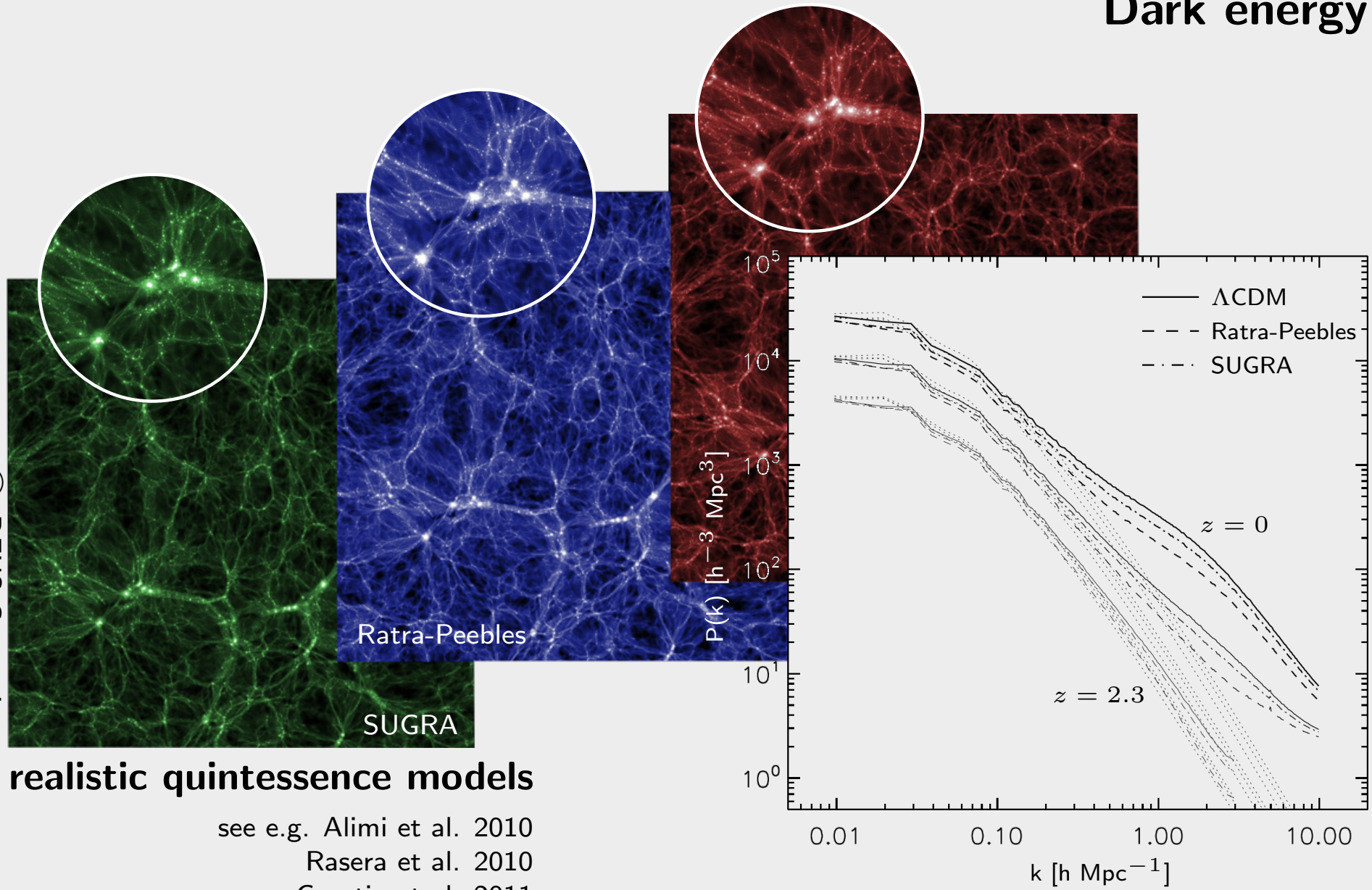
Dark energy



realistic quintessence models

see e.g. Alimi et al. 2010
Rasera et al. 2010
Courtin et al. 2011

Dark energy



realistic quintessence models

see e.g. Alimi et al. 2010
Rasera et al. 2010
Courtin et al. 2011

Rasera et al. 2010

DEMNUni

Dark Energy and Massive Neutrino Universe

Suite of 11 simulations:

Massive neutrinos: $M_\nu = 0.00, 0.16, 0.32$ eV

Evolving **dark energy** $(w_0, w_\mathrm{a}) = (-0.9, \pm 0.3)$
$= (-1.1, \pm 0.3)$
$= (-1.0, 0.0)$

Shared by all models:

$\Omega_\mathrm{m} = 0.32, \Omega_\mathrm{b} = 0.05, h = 0.67, n_s = 0.96, A_s = 2.126 \times 10^{-9}$

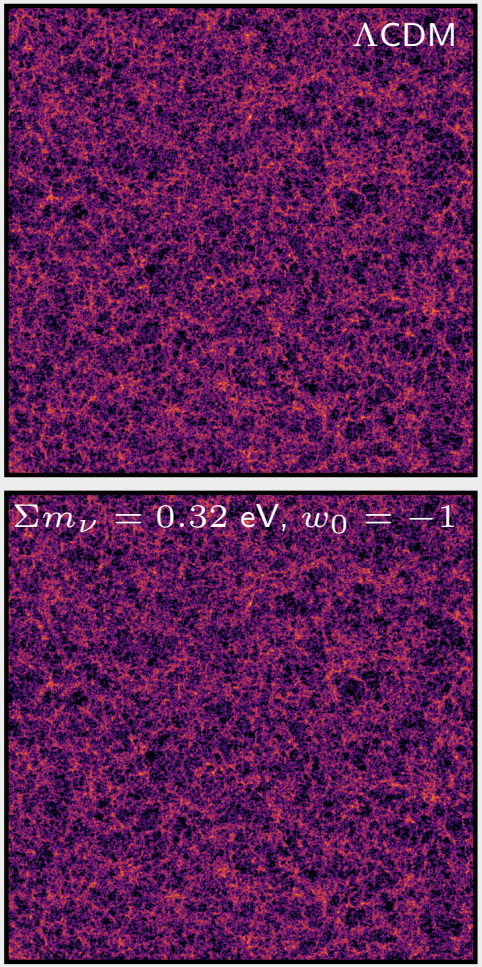
GADGET-3 + ν component (Viel et al. 2010)

Box size = 2 h^{-1} Gpc

2×2048^3 particles (DM + ν)

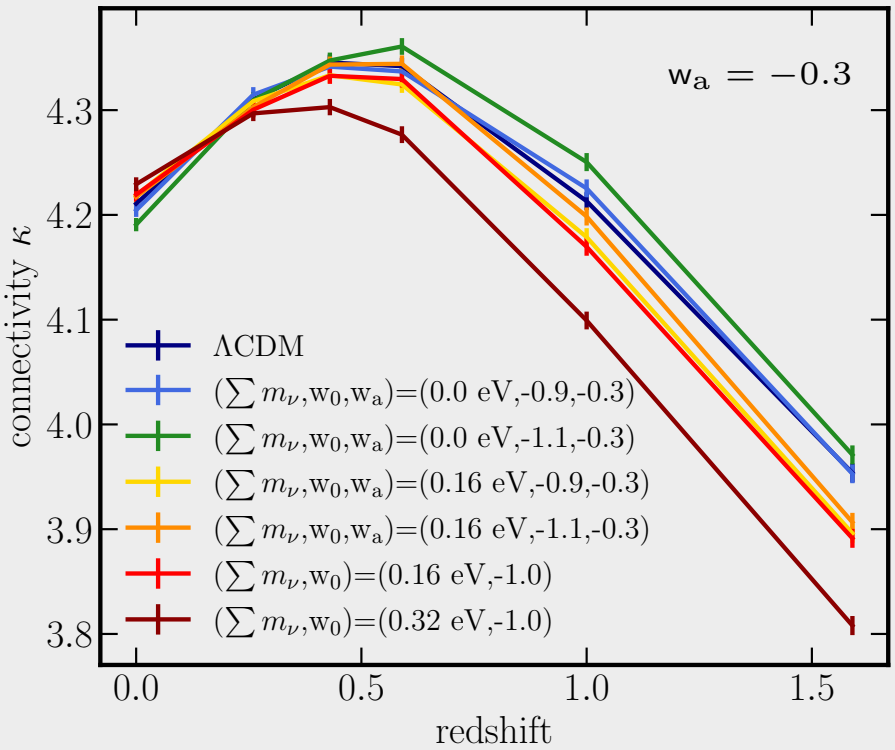
Softening length $\epsilon = 20 h^{-1}$ kpc

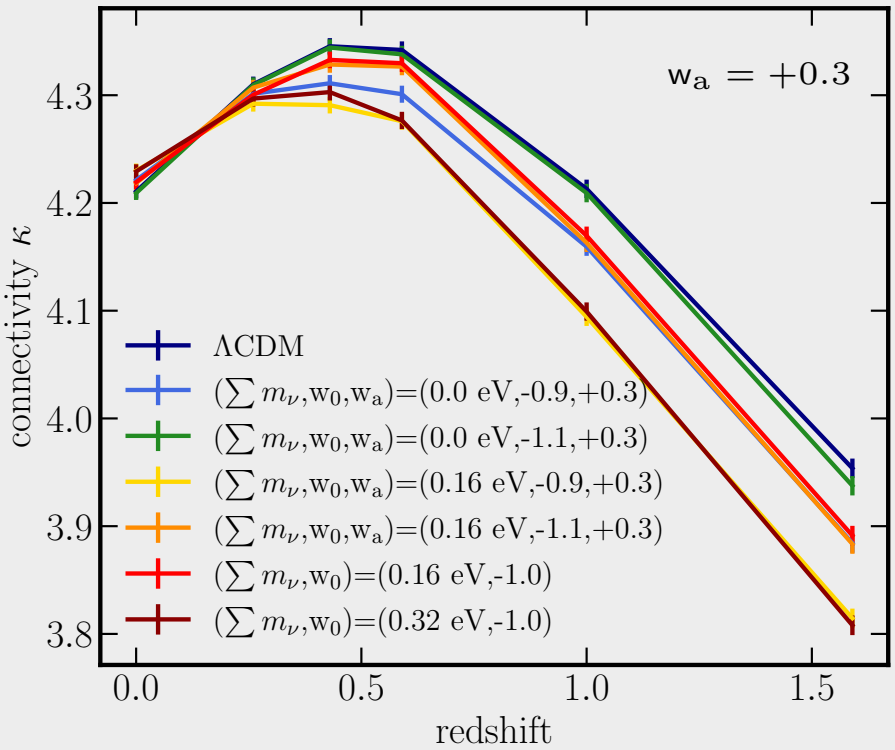
Minimum halo mass $\sim 2.5 \times 10^{12} h^{-1}$ $\mathrm{M}_\odot$



Castorina et al. 2015
Carbone et al. 2016

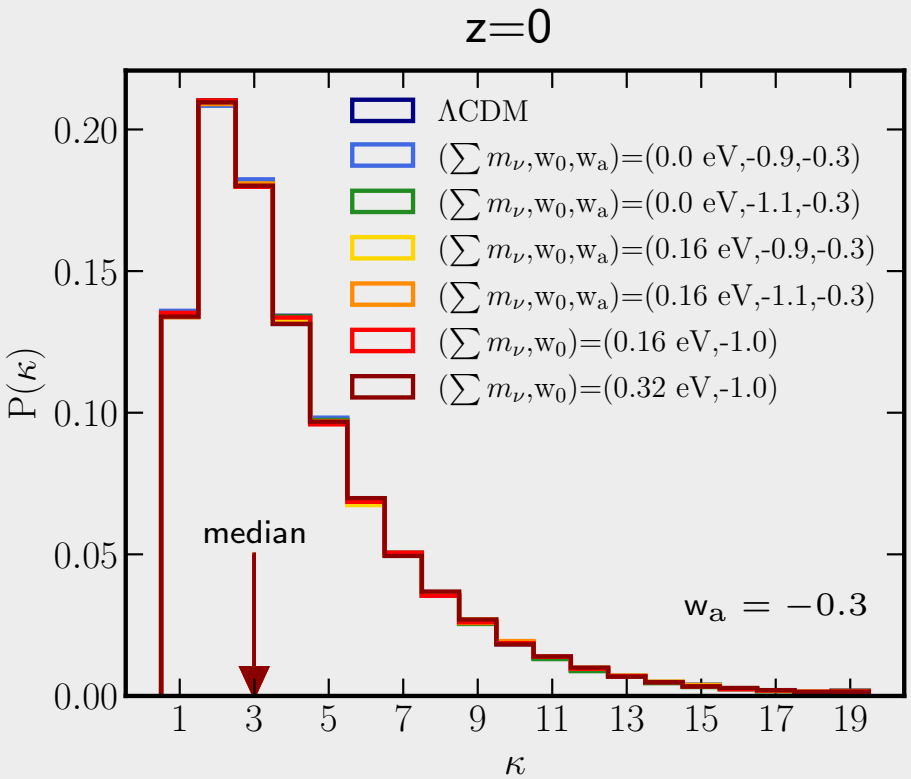
Connectivity of halos
Redshift evolution

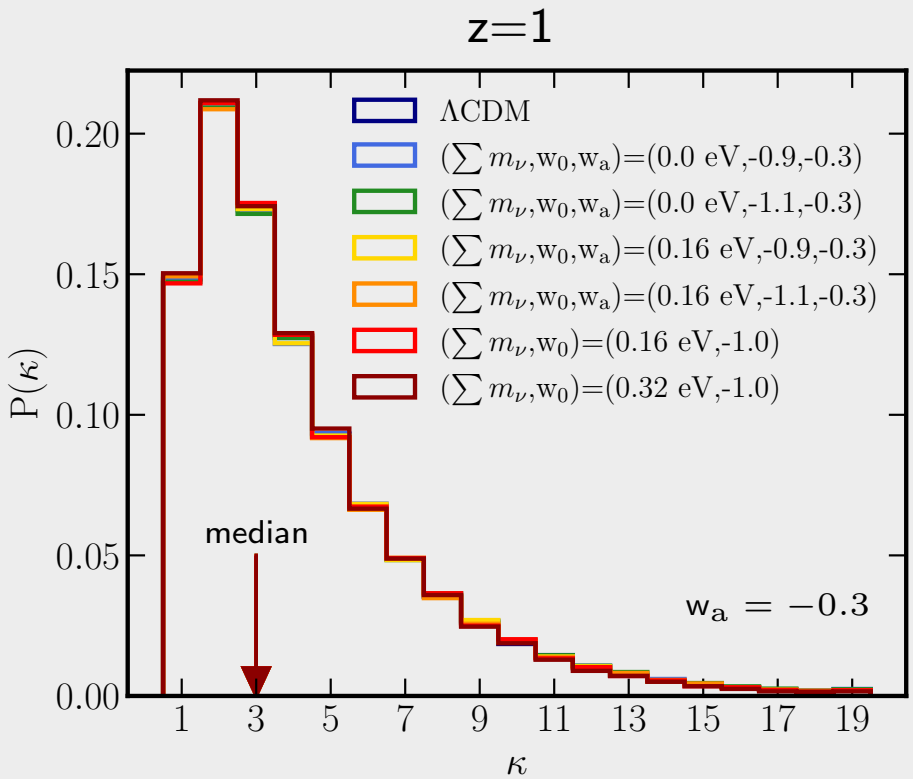




preliminary

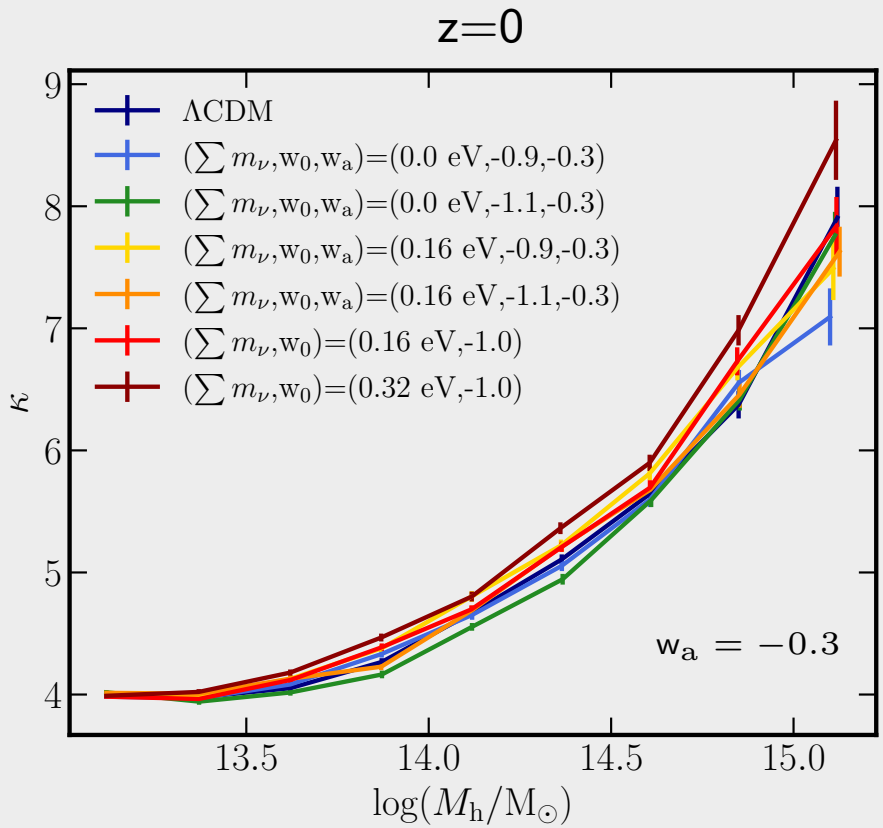
Connectivity of halos
Full distribution

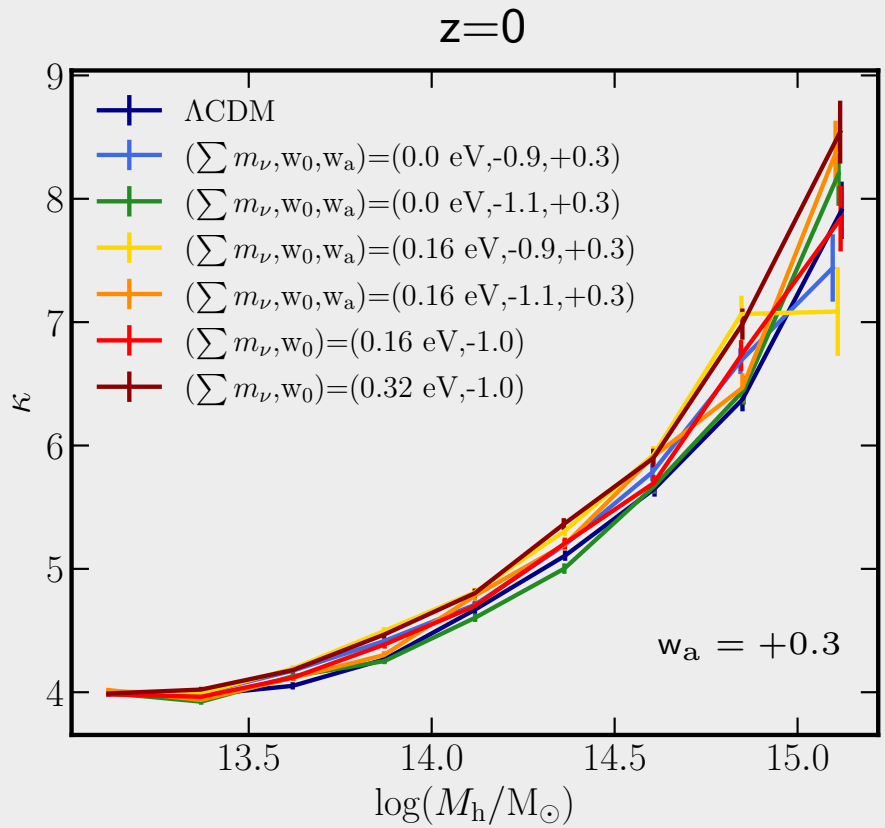




preliminary

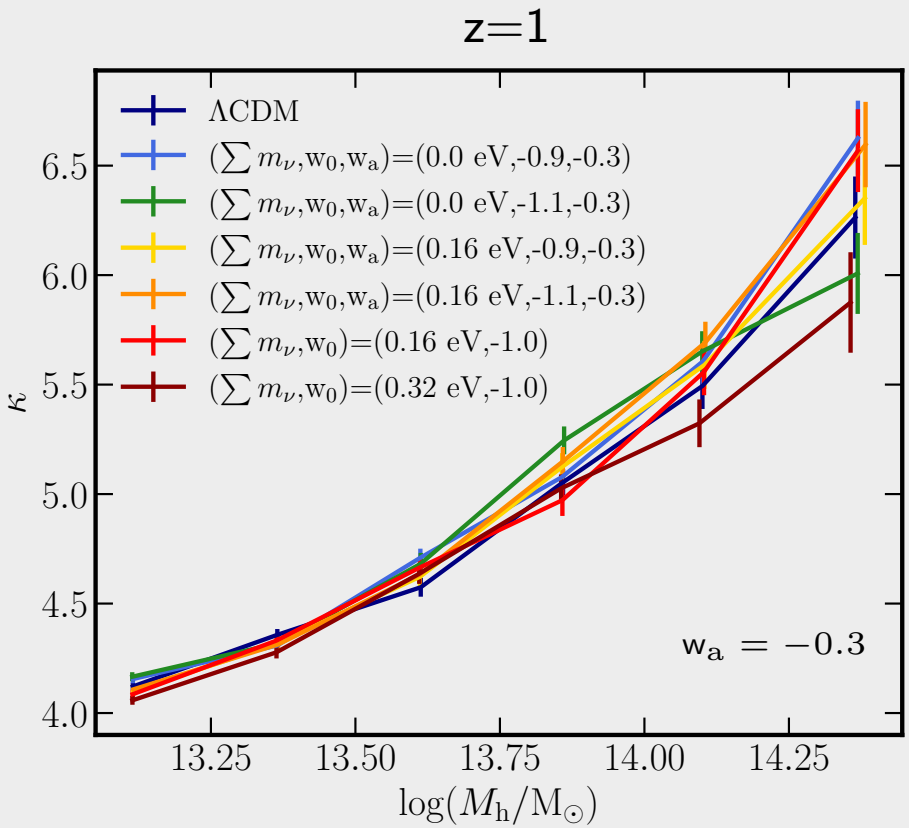
Connectivity of halos
Mass dependence I

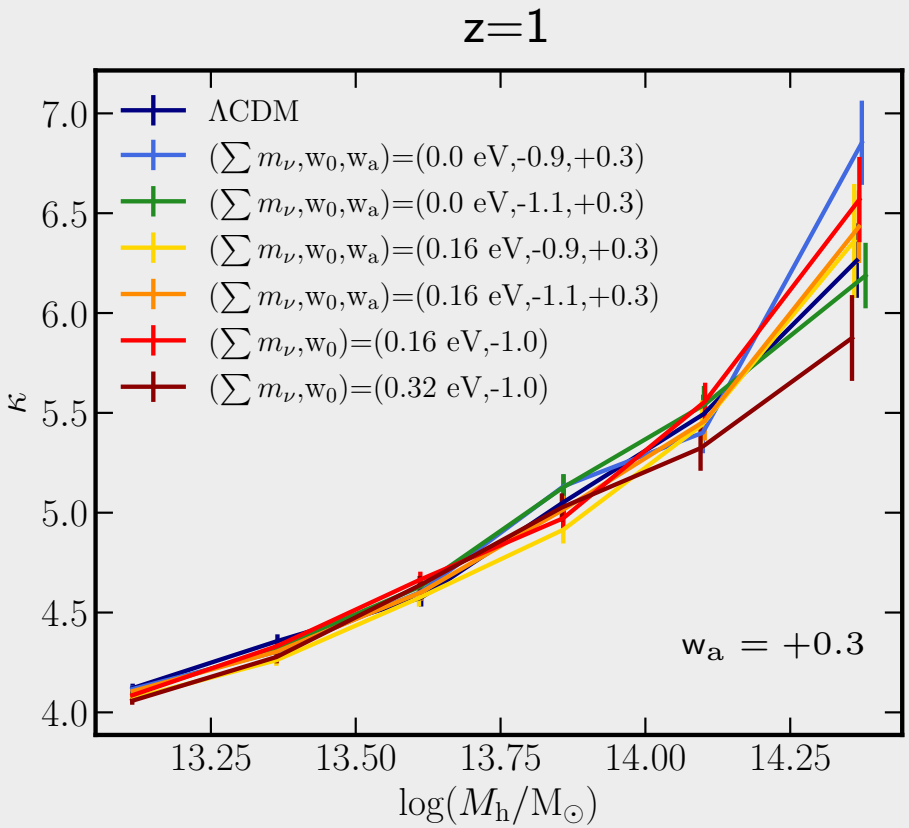




preliminary

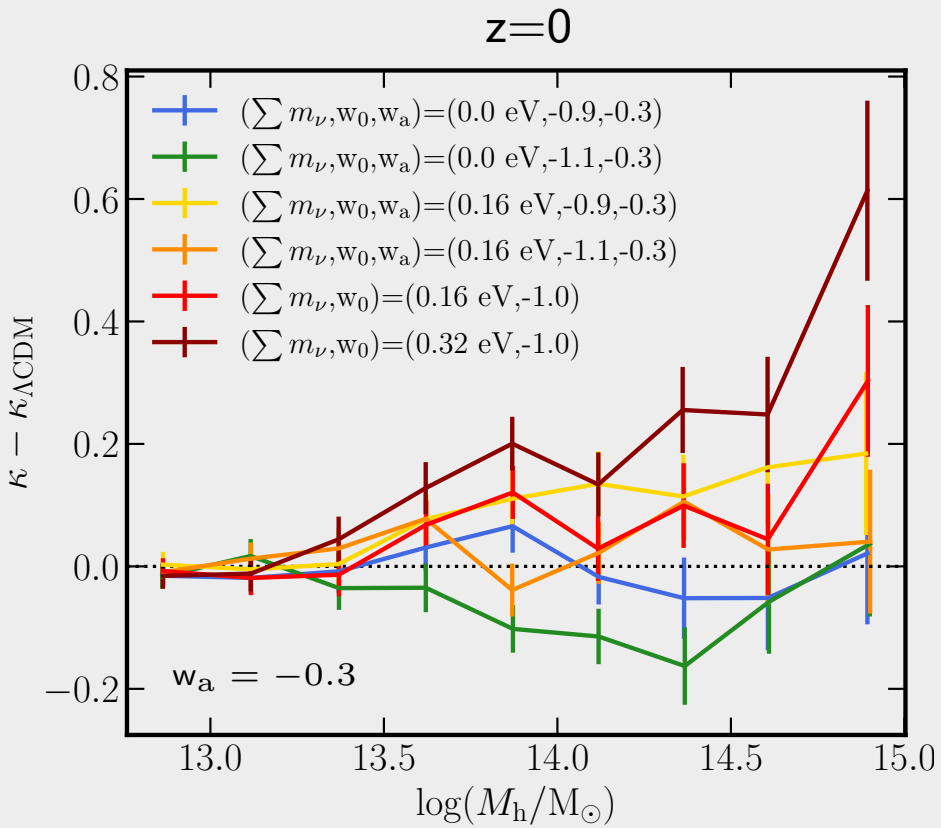
Connectivity of halos
Mass dependence I

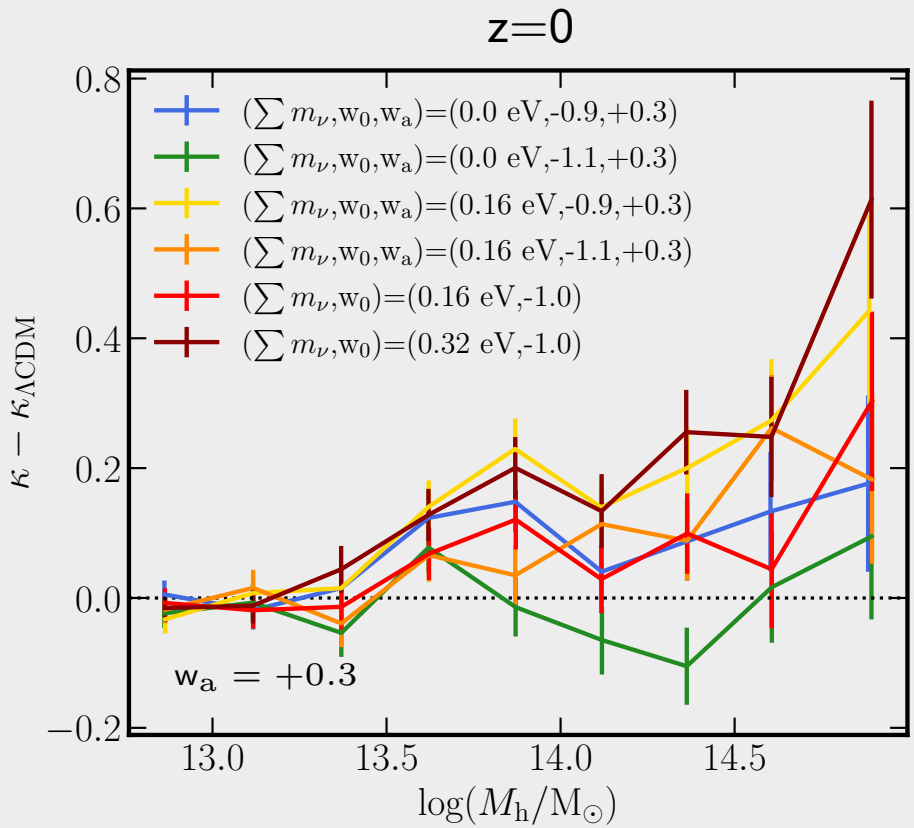




preliminary

Connectivity of halos
Mass dependence II

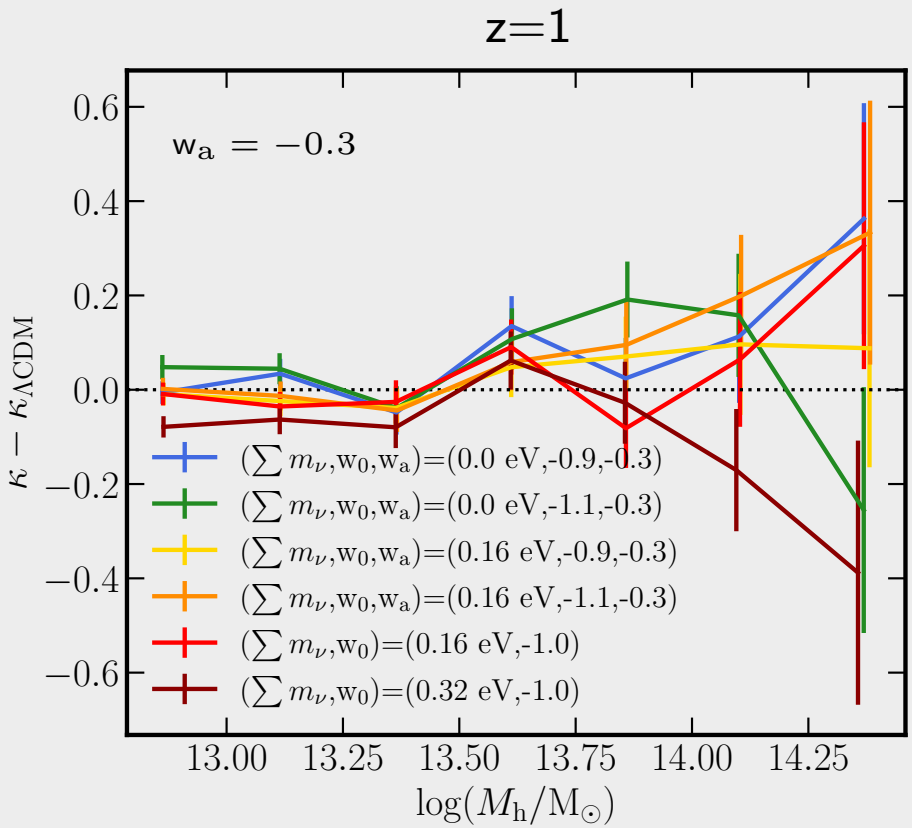


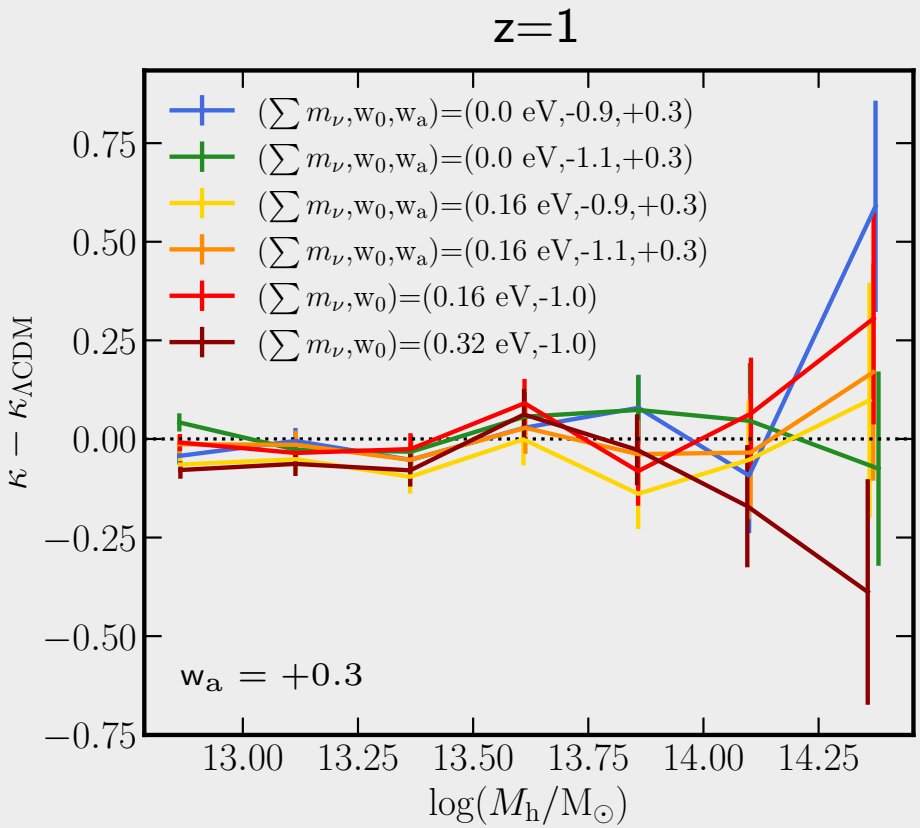


preliminary

ΛCDM degenerate with $(\Sigma m_\nu, w_0, w_a)$=(0.16 eV,-1.1,-0.3)
but alslo $(\Sigma m_\nu, w_0, w_a)$=(0.0 eV,-0.9,-0.3) and (0.0 eV,-1.1,+0.3)

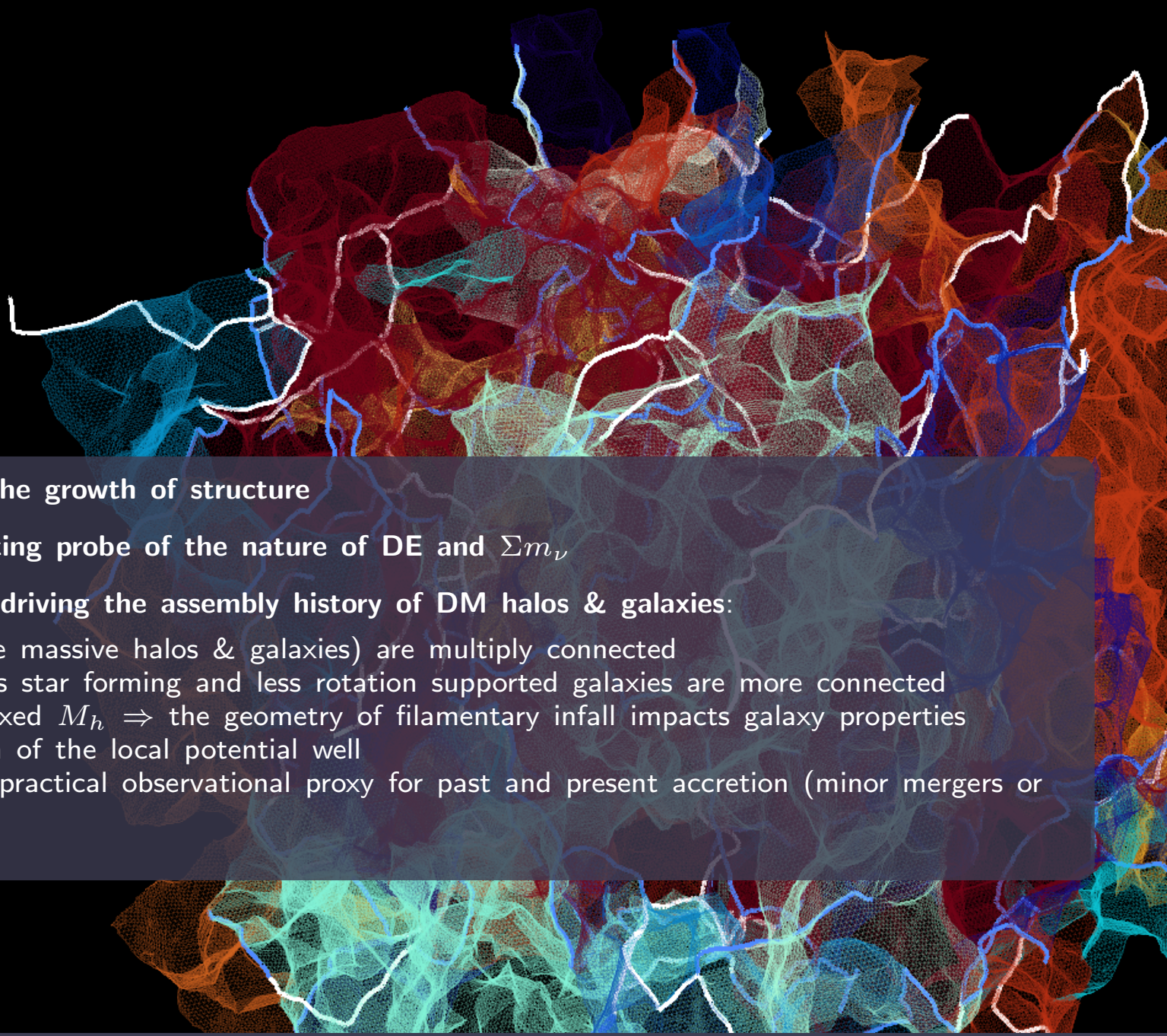
Connectivity of halos
Mass dependence II





preliminary

degeneracy broken for $(\Sigma m_\nu, w_0, w_a)$=(0.16 eV,-1.1,-0.3) and (0.0 eV,-0.9,-0.3)



Connectivity

Natural probe of the growth of structure

Potentially interesting probe of the nature of DE and Σm_ν

Critical ingredient driving the assembly history of DM halos & galaxies:

- rares peaks (more massive halos & galaxies) are multiply connected
- at fixed $M_\star$: less star forming and less rotation supported galaxies are more connected
- same trends at fixed M_h $\Rightarrow$ the geometry of filamentary infall impacts galaxy properties beyond the depth of the local potential well
- connectivity is a practical observational proxy for past and present accretion (minor mergers or diffuse infall)