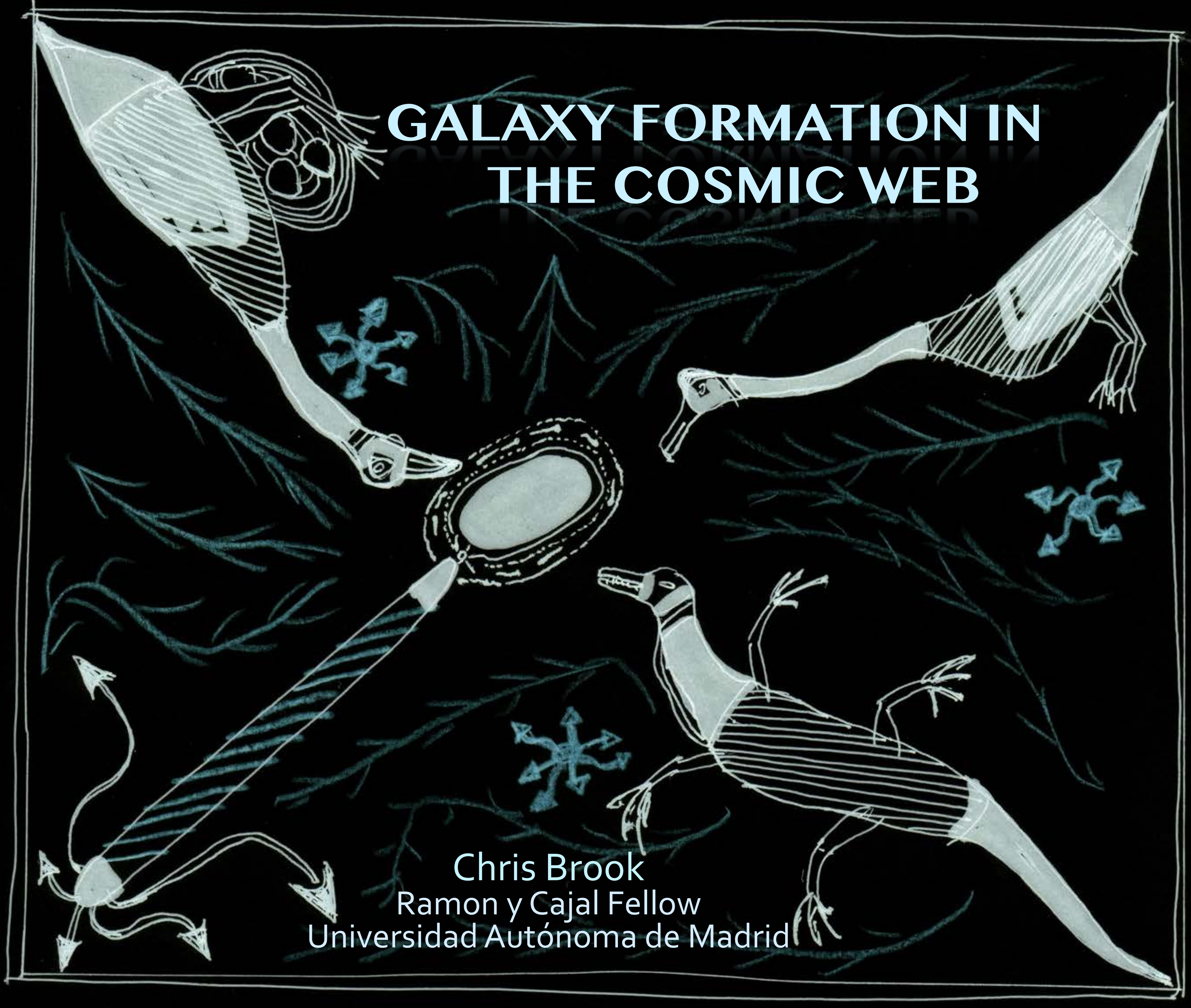
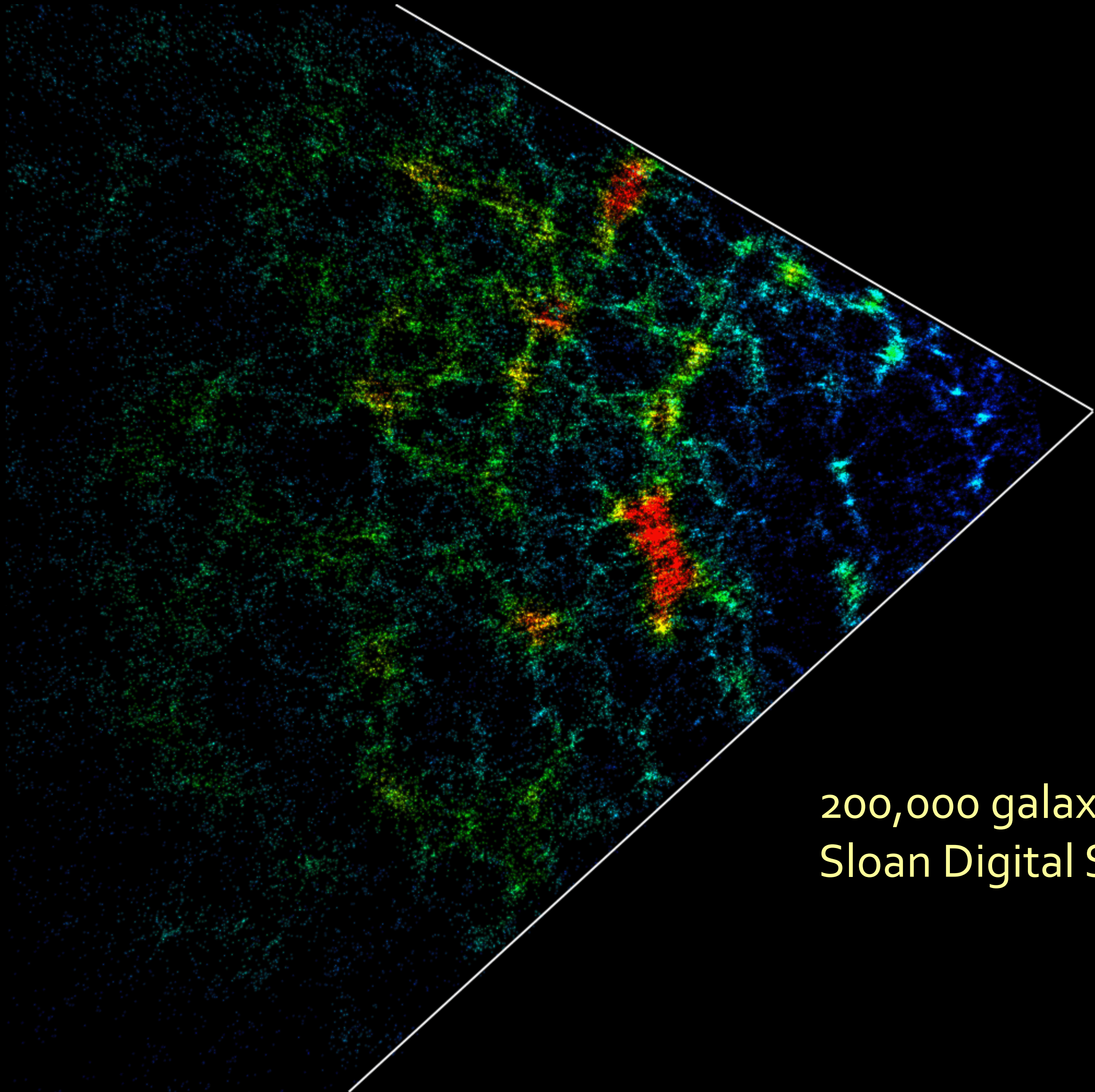
GALAXY FORMATION IN THE COSMIC WEB



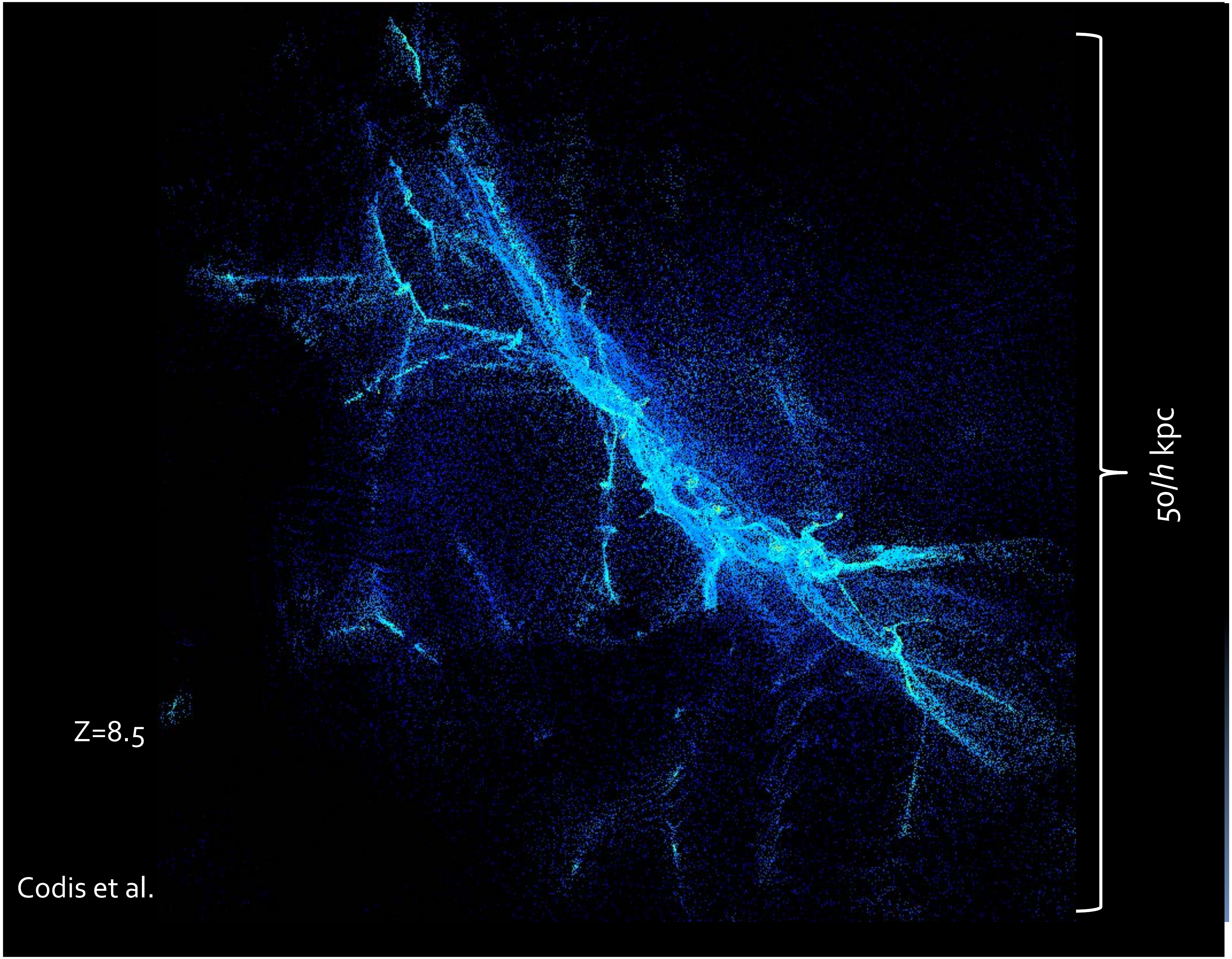
Chris Brook
Ramon y Cajal Fellow
Universidad Autónoma de Madrid

Outline

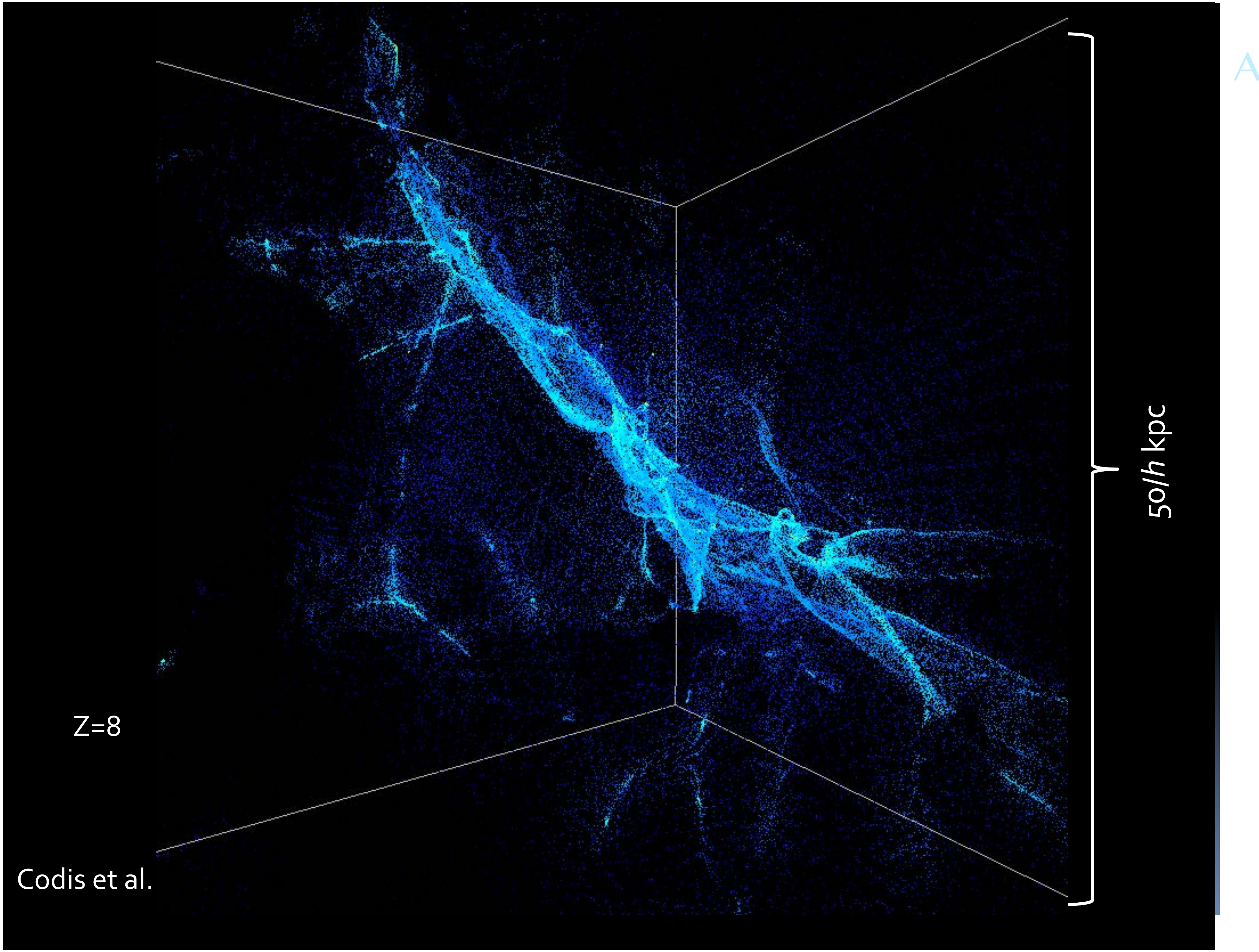
- Cosmic web and mass accretion
- Early disc formation
- Inflows/outflows and angular momentum
- Matter distributions: do outflows affect Dark Matter?

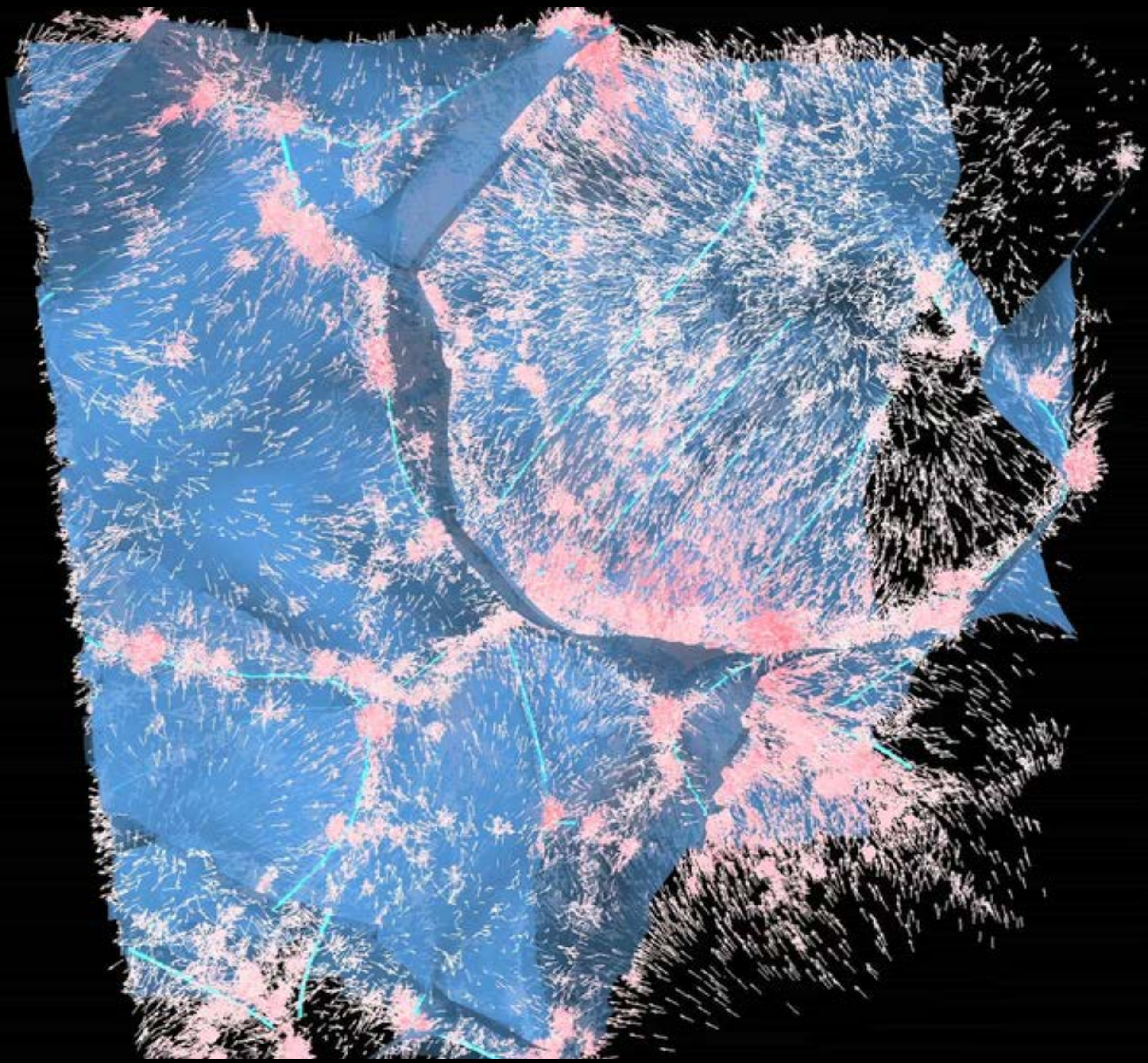


200,000 galaxies from
Sloan Digital Sky Survey

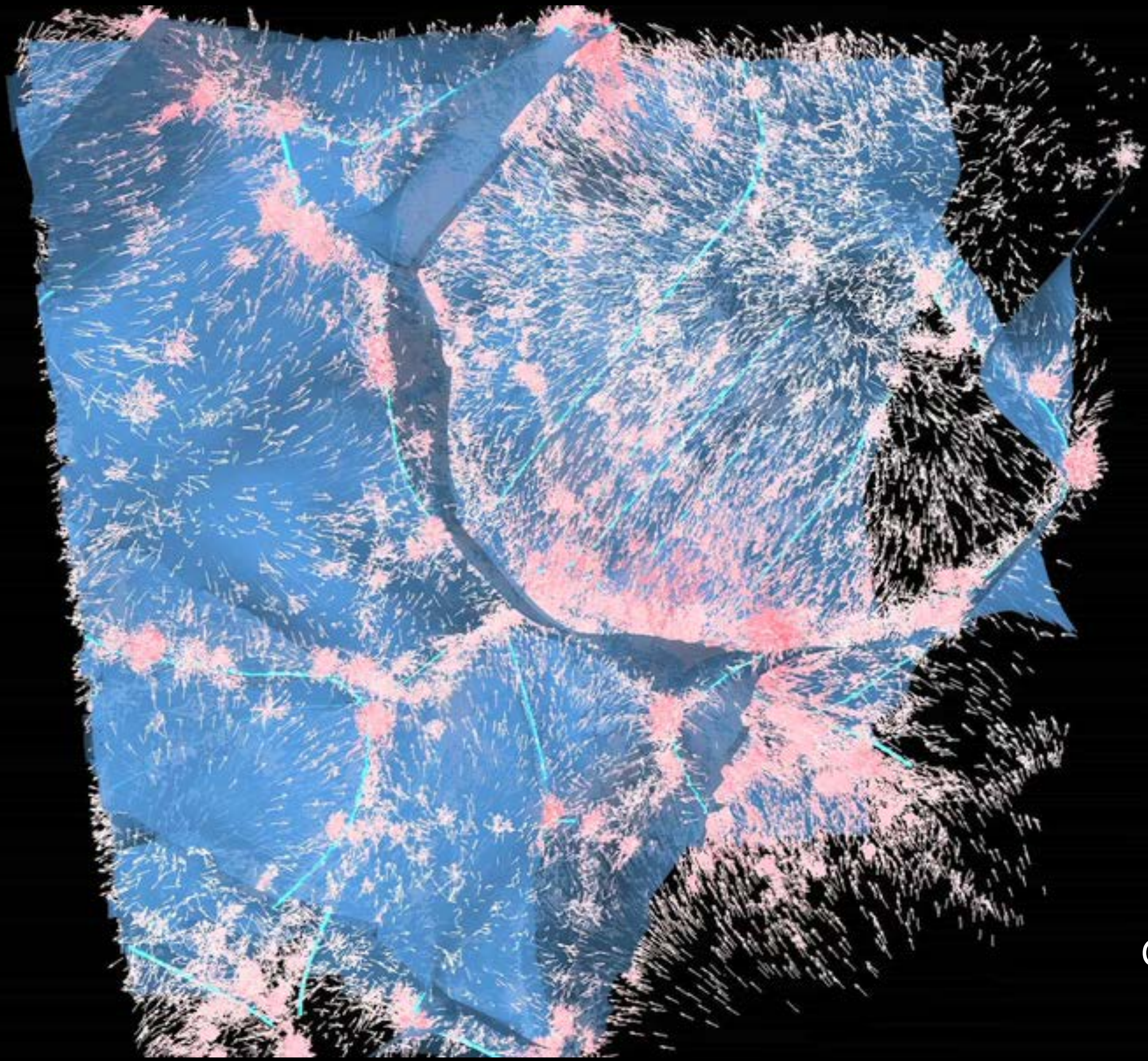


50/h kpc
Z=8.5
Codis et al.


A
50/h kpc
Z=8
Codis et al.

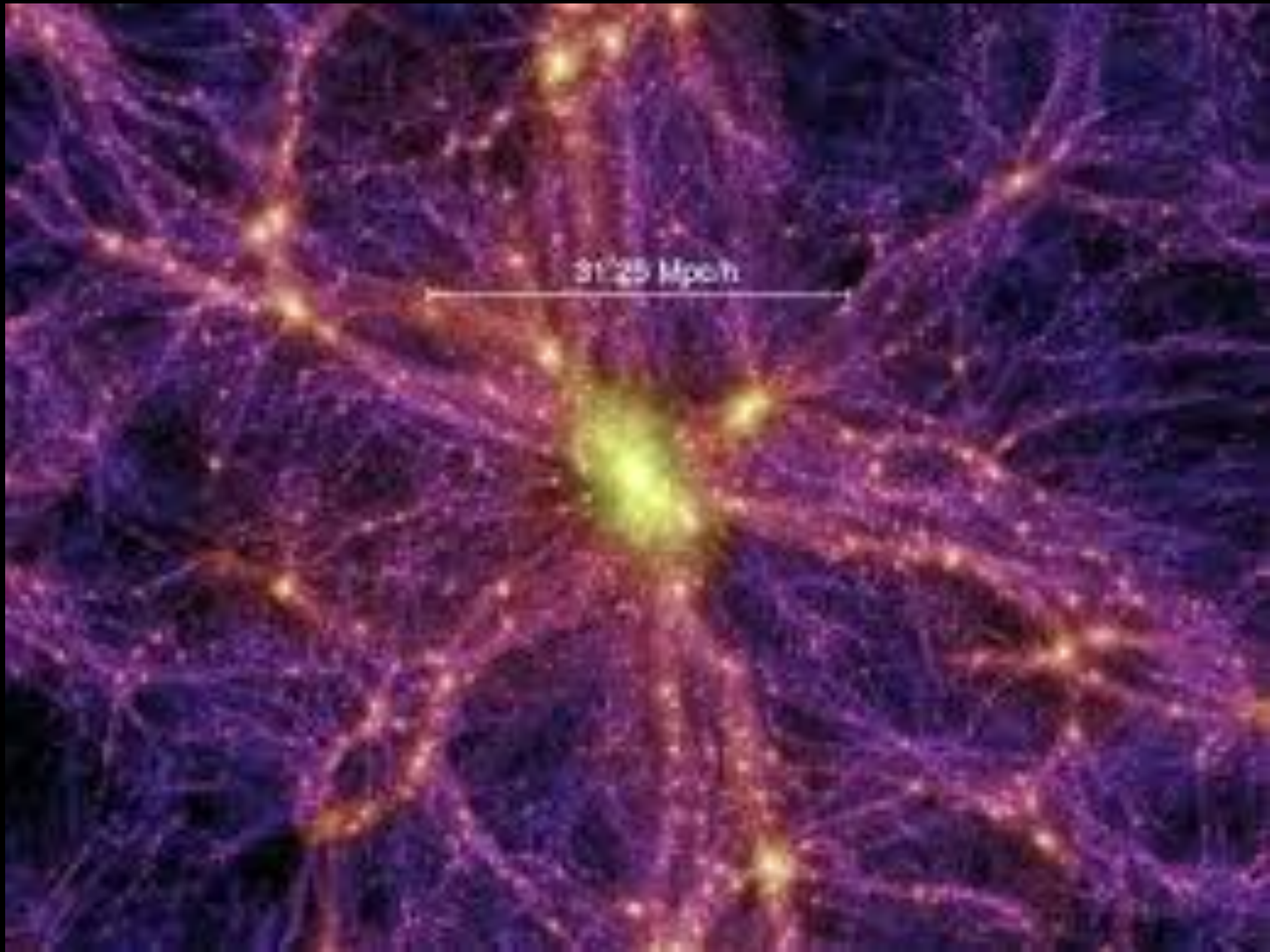


Voids: 15% of mass 78% of volume
Walls: 25% of mass 18% of volume Cautun et al. 2014

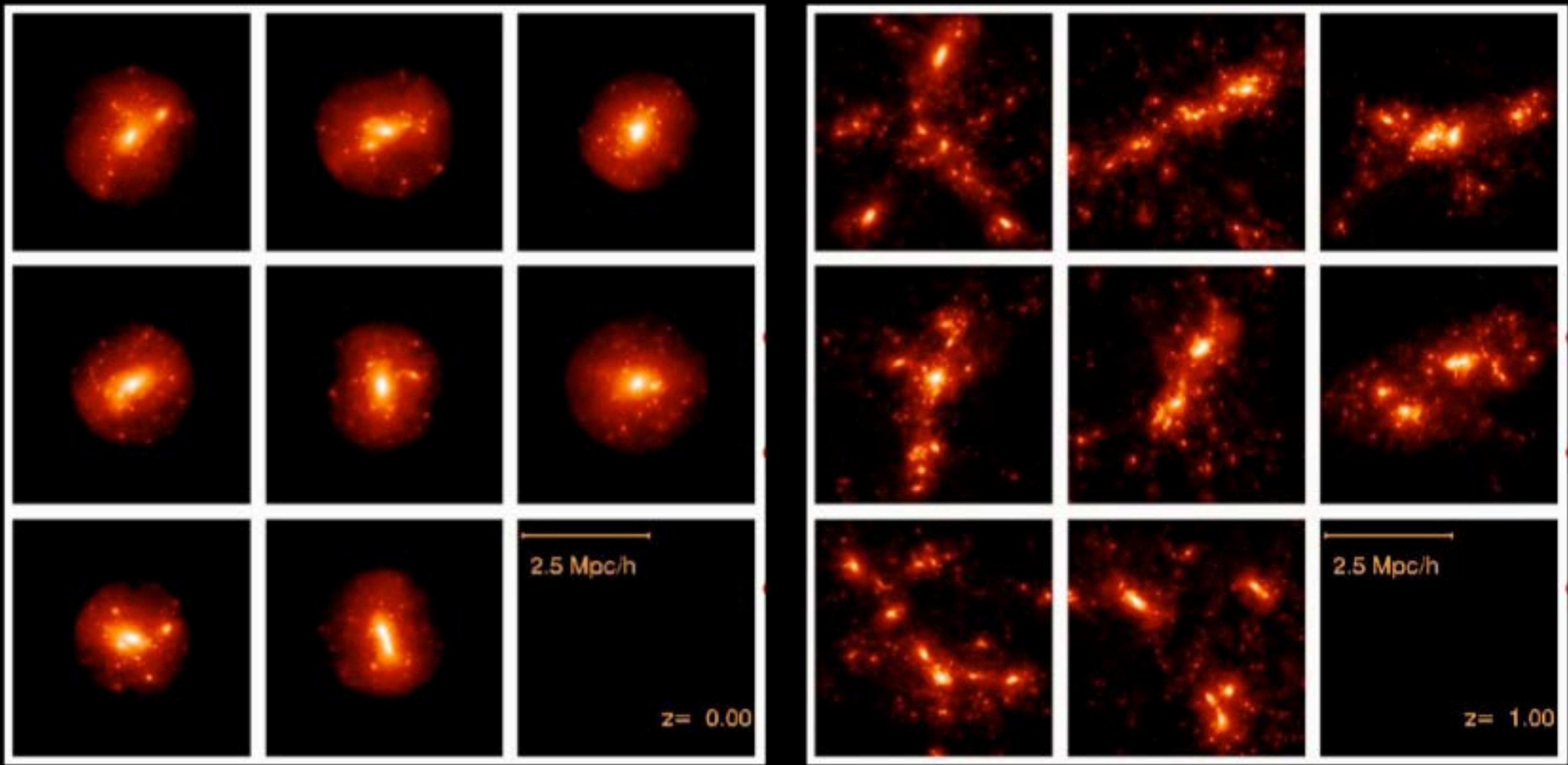


Voids & Walls: Few halos with Mass >10^{12}Msun

Cautun et al. 2014



Filaments: 50% of mass 6% of volume
Clusters: 10% of mass

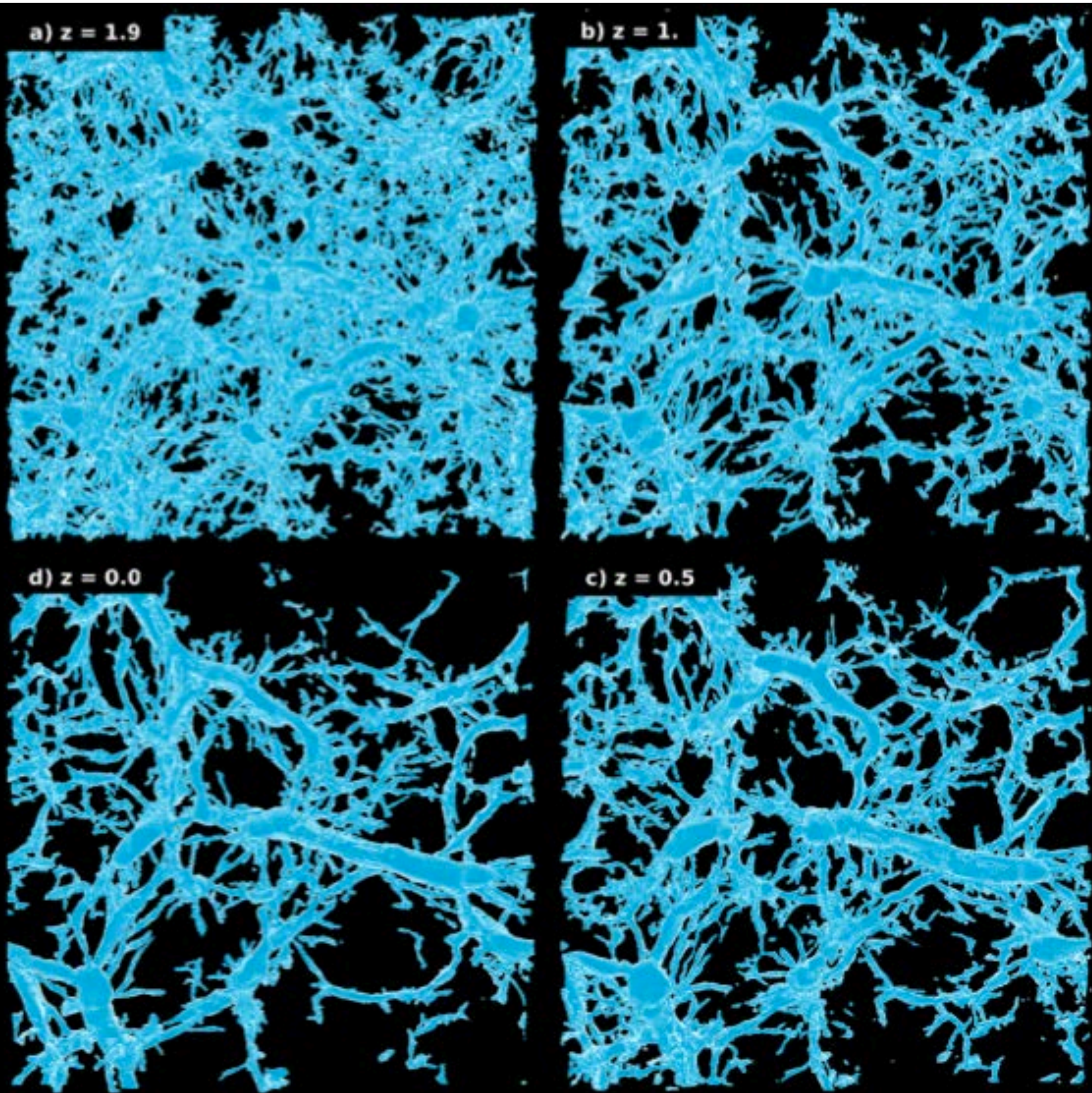


Z=0

Z=1

credit: S. White

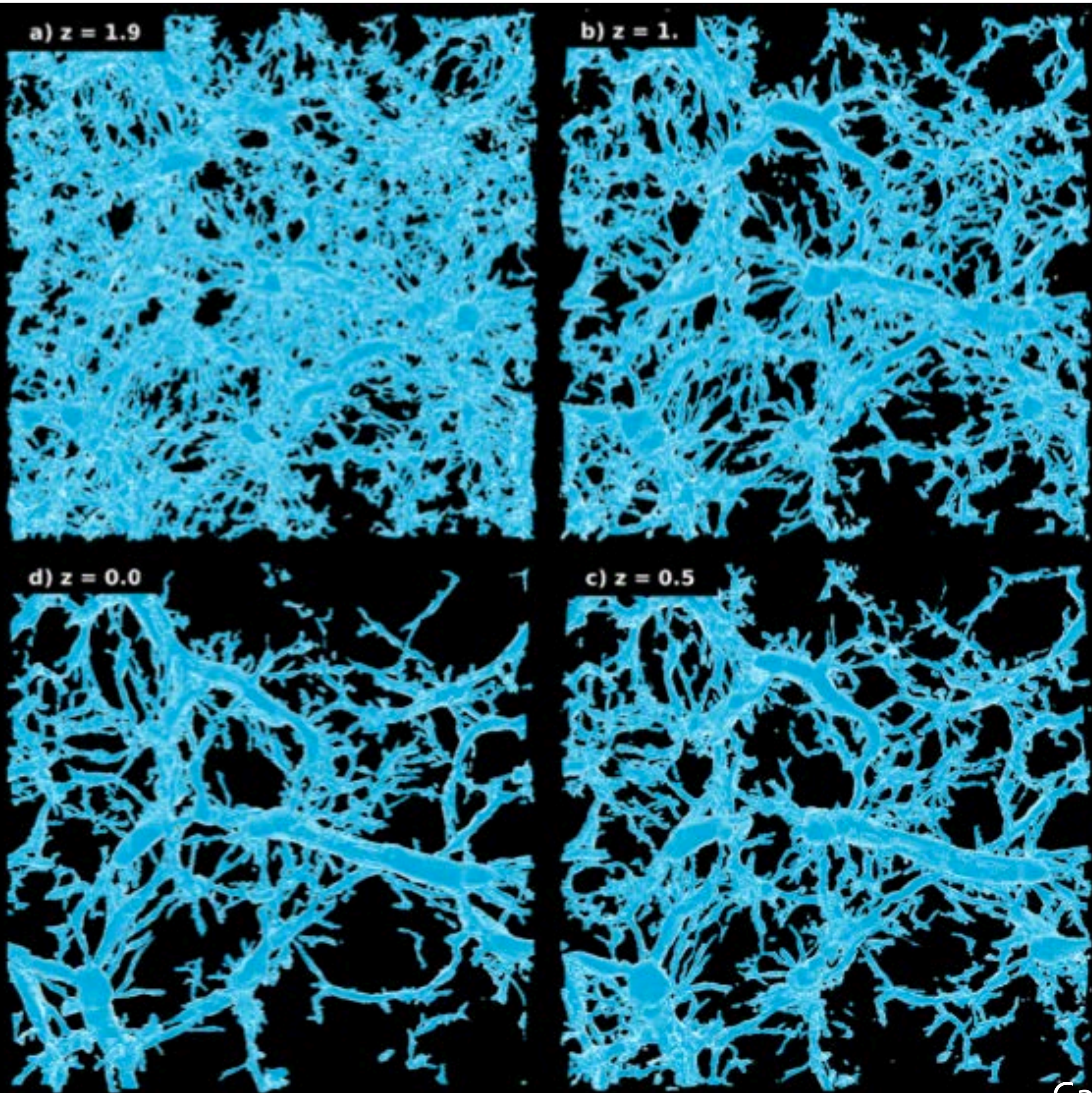
Clusters become significant at z<~0.5
Clusters are fed by filaments



Cautun et al. 2014

Filaments and Walls in place by z~2

Many small filaments at high z

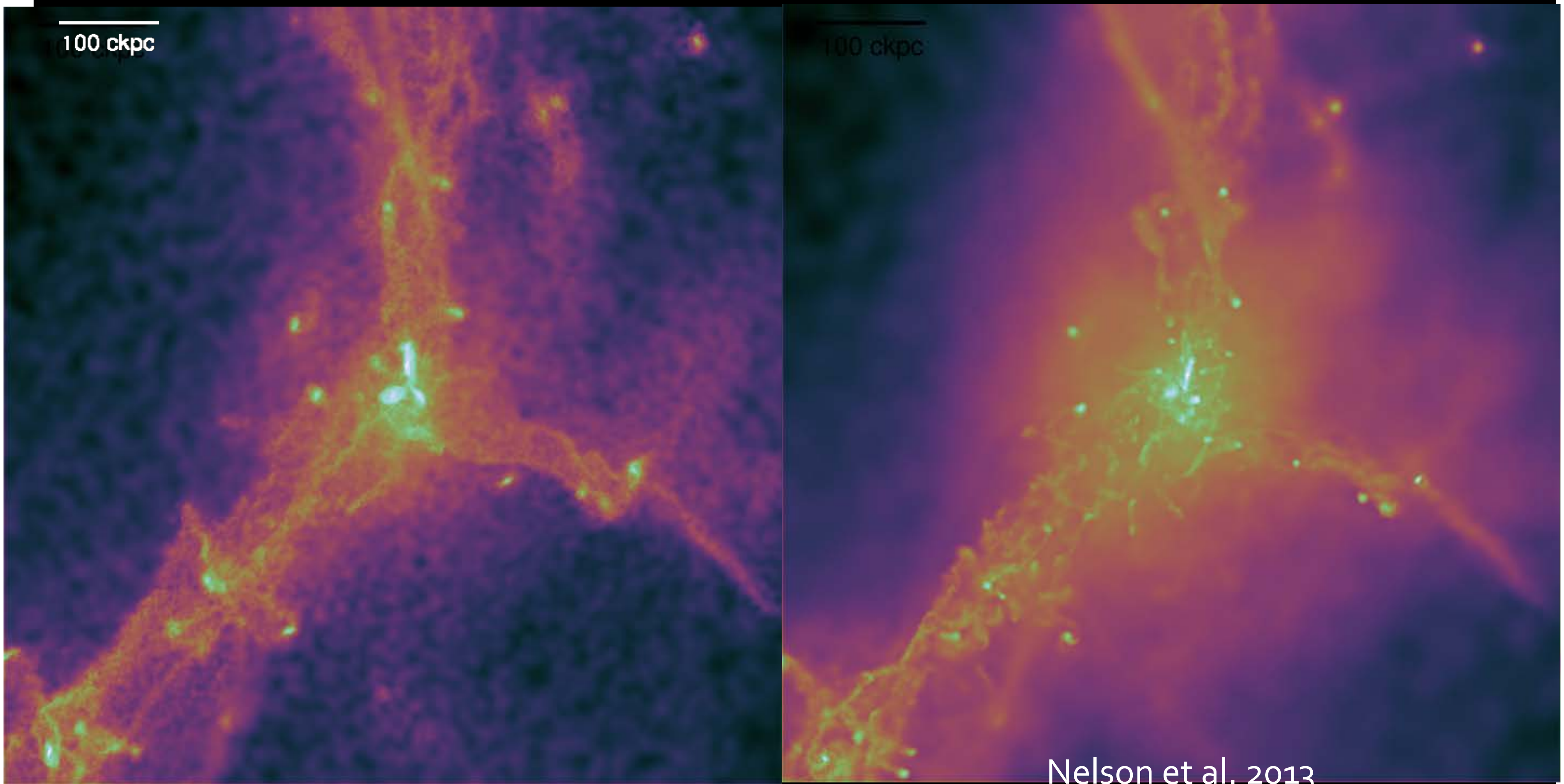


Cautun et al. 2014

High z: filaments are dominated by small scale structures
At z=0: small scale structures in filaments are mostly gone

Hydrodynamical Simulations

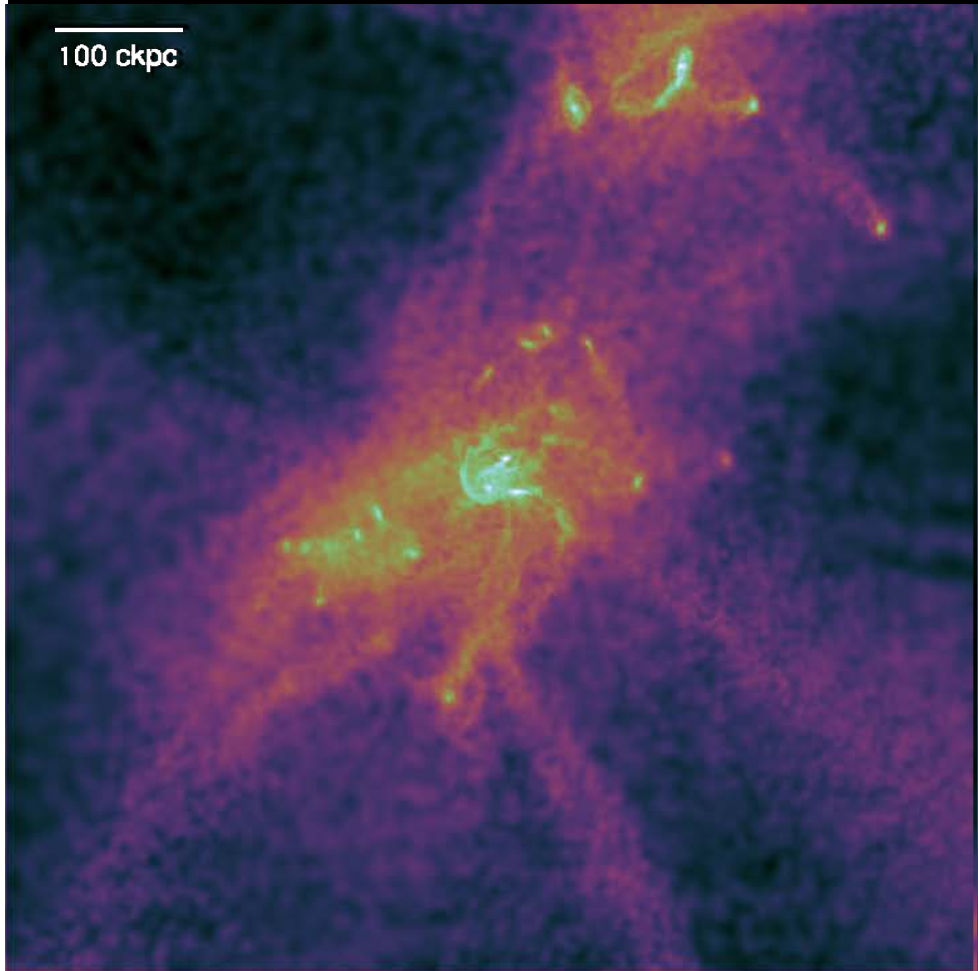
z=3 Arepo Gadget

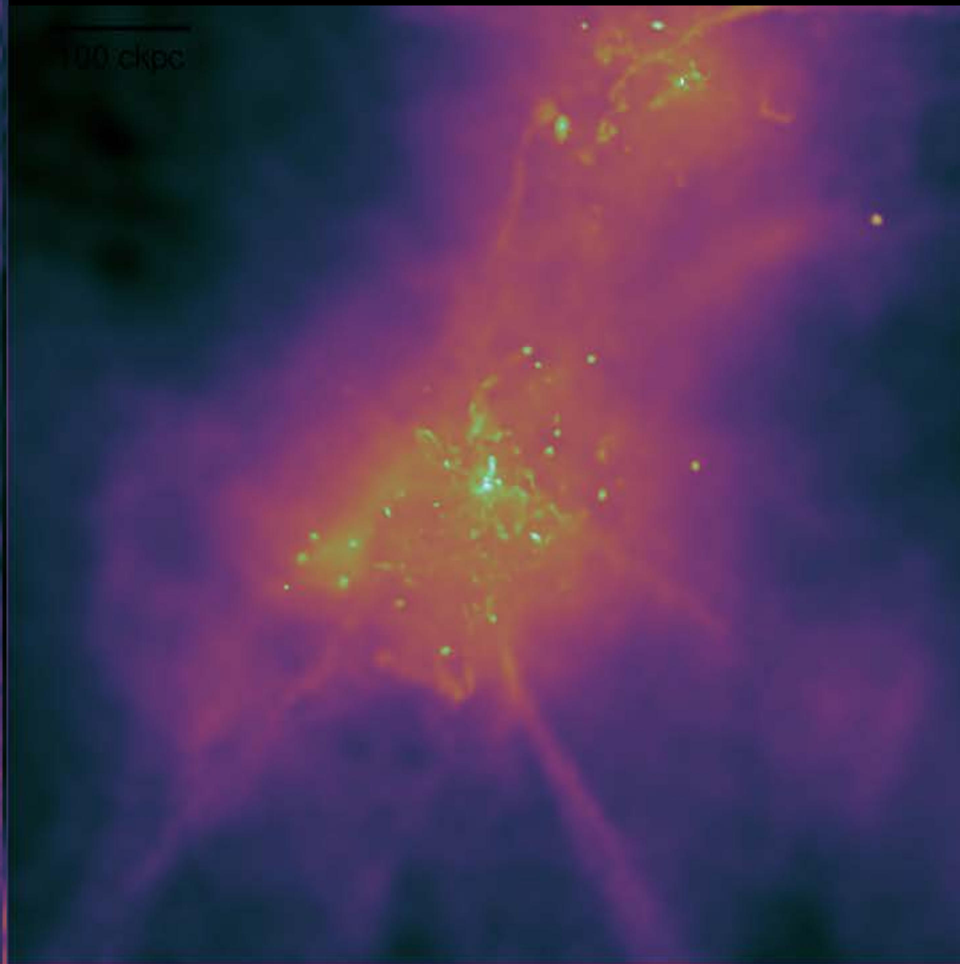


Nelson et al. 2013

Hydrodynamical Simulations

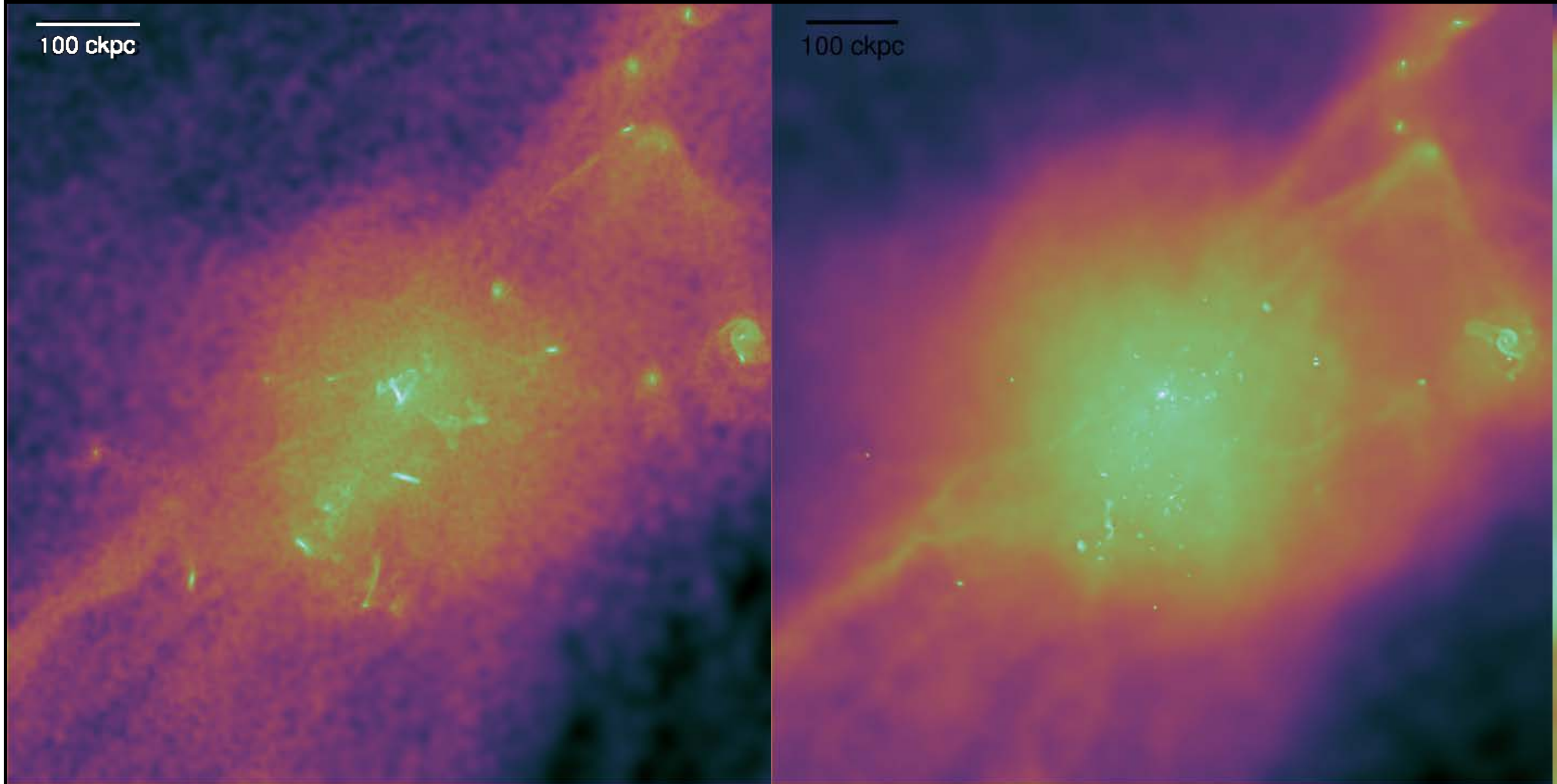
z=2 Arepo Gadget

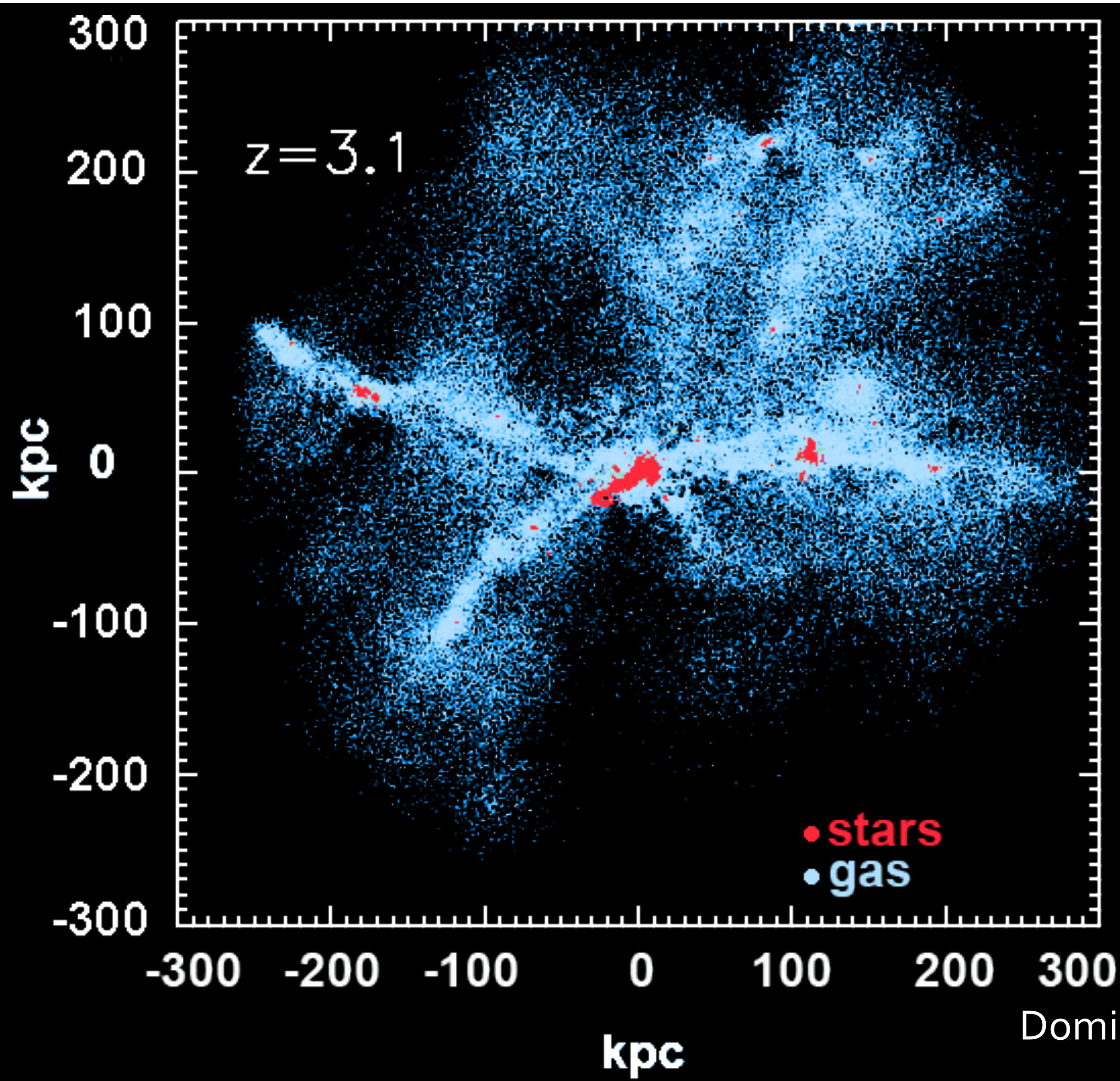




Hydrodynamical Simulations

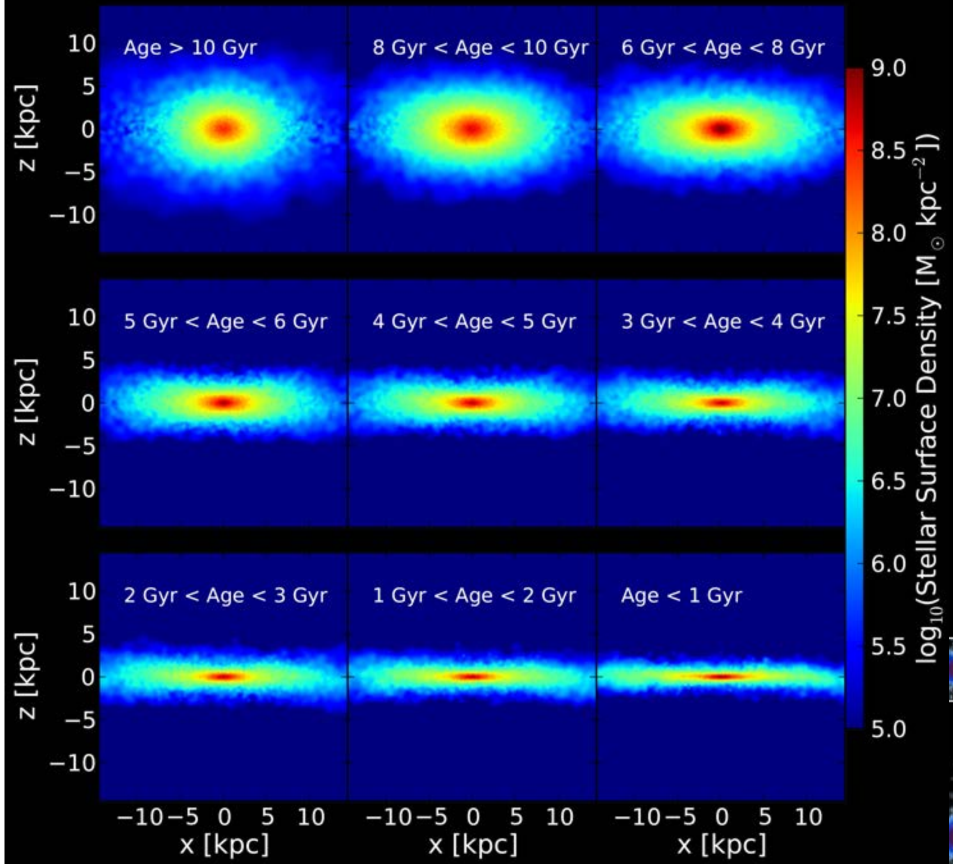
z=1 Arepo Gadget





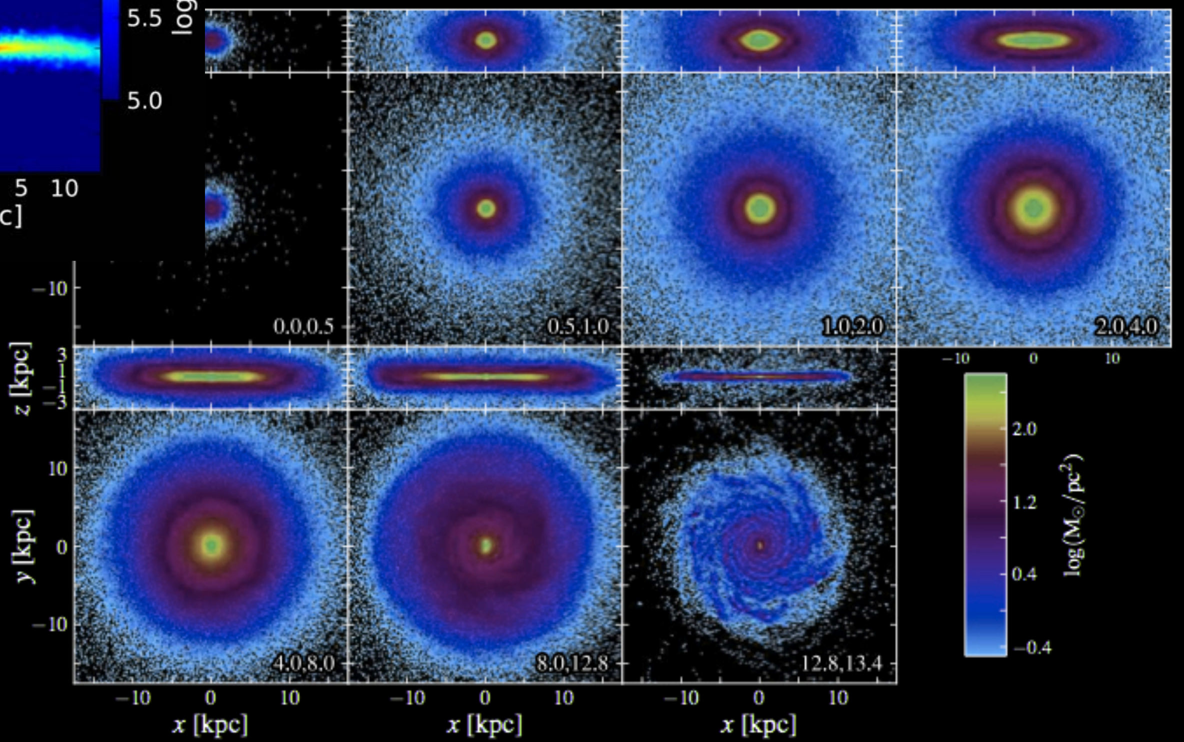
Dominguez-Tenriero et al. 2015

Progenitor baryons of a disc galaxy
Mass is fed by filaments, which contain small structures



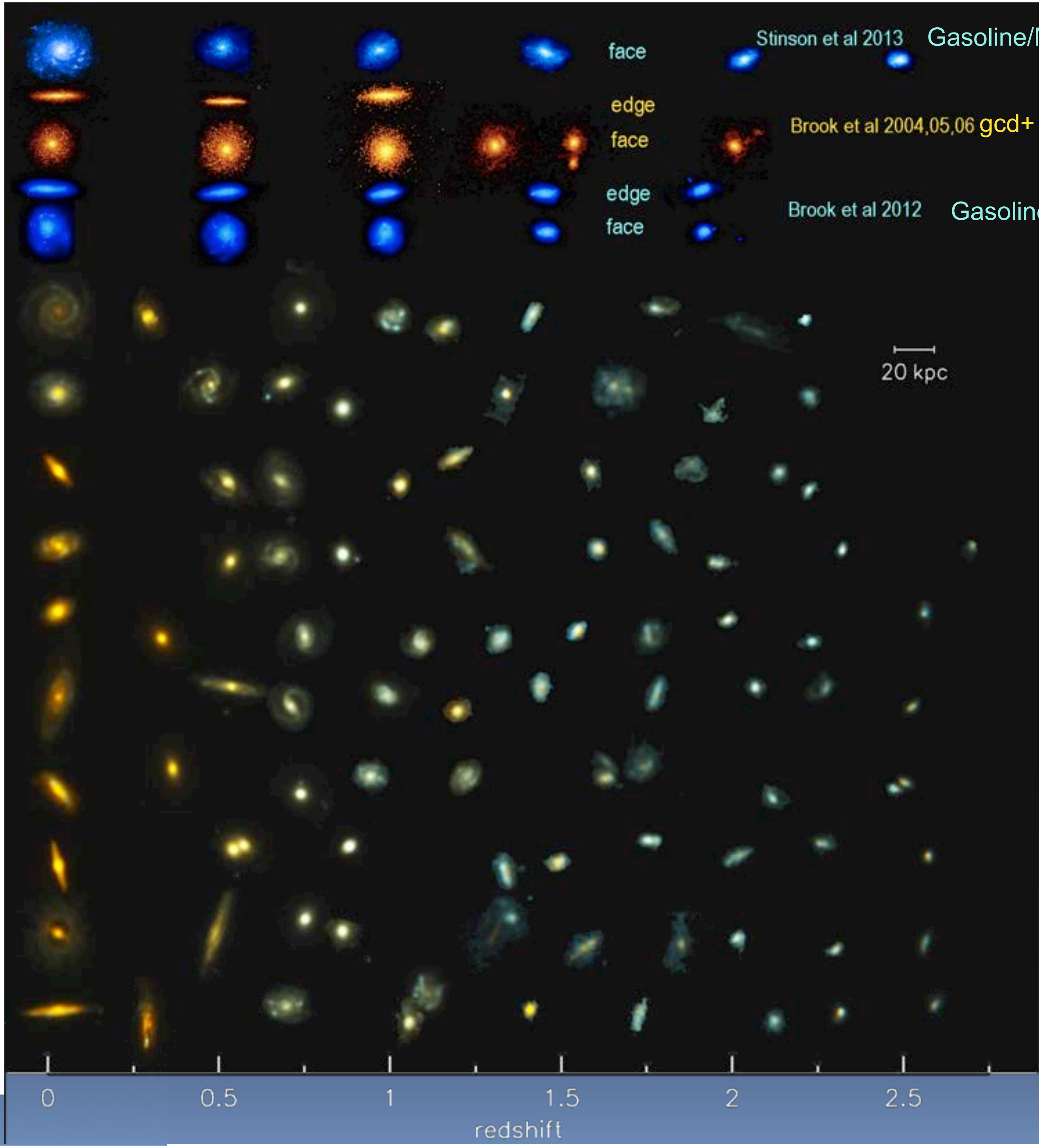
Brook et al. 2004, 2005, 2012
Stinson et al. 2013

Stinson et al. 2013



Bird et al. 2013

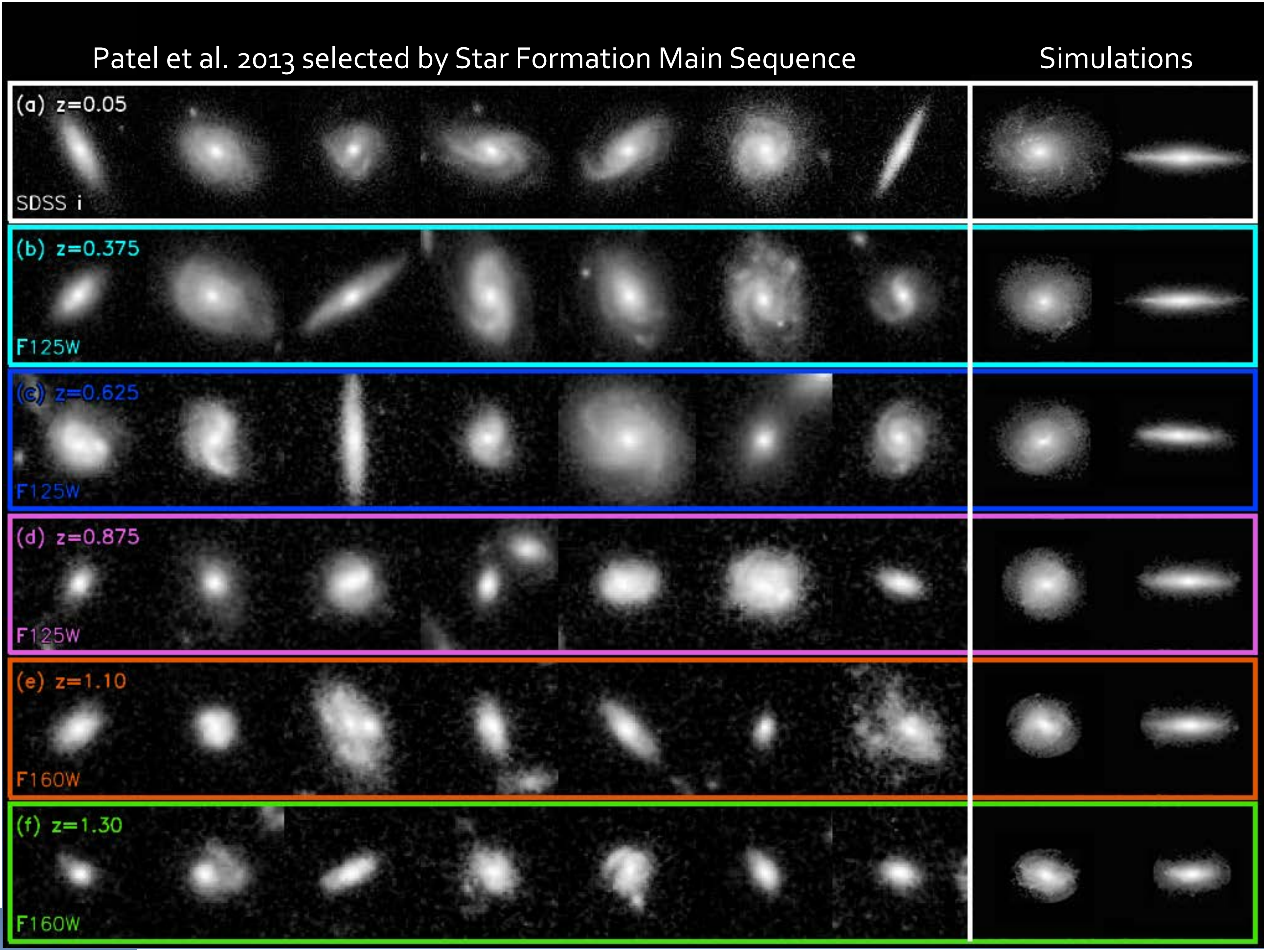
See also Minchev 2012, 2013



Simulations
Different codes and ICs

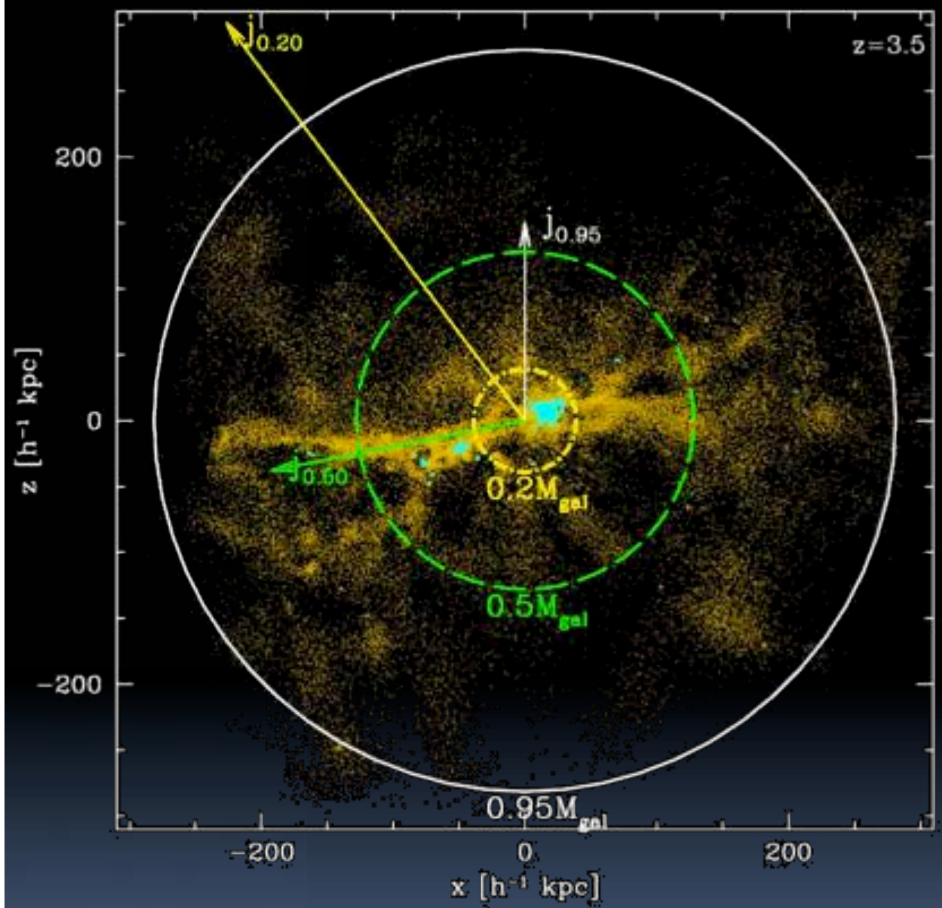
Observations:
Van Dokkum et al 2013

MW progenitors selected by number density

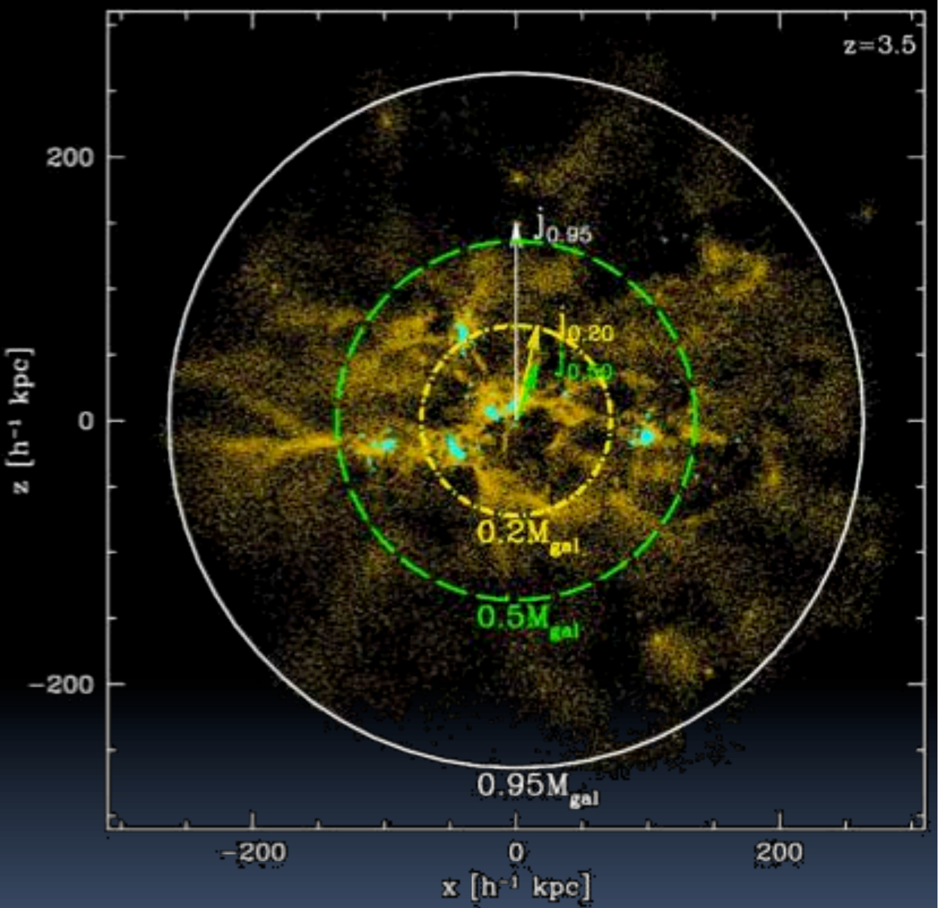

Patel et al. 2013 selected by Star Formation Main Sequence
Simulations
(a) z=0.05
SDSS i
(b) z=0.375
F125W
(c) z=0.625
F125W
(d) z=0.875
F125W
(e) z=1.10
F160W
(f) z=1.30
F160W

Filaments and disc angular momentum

Angular momentum of different shells at turn around (z=3.5)



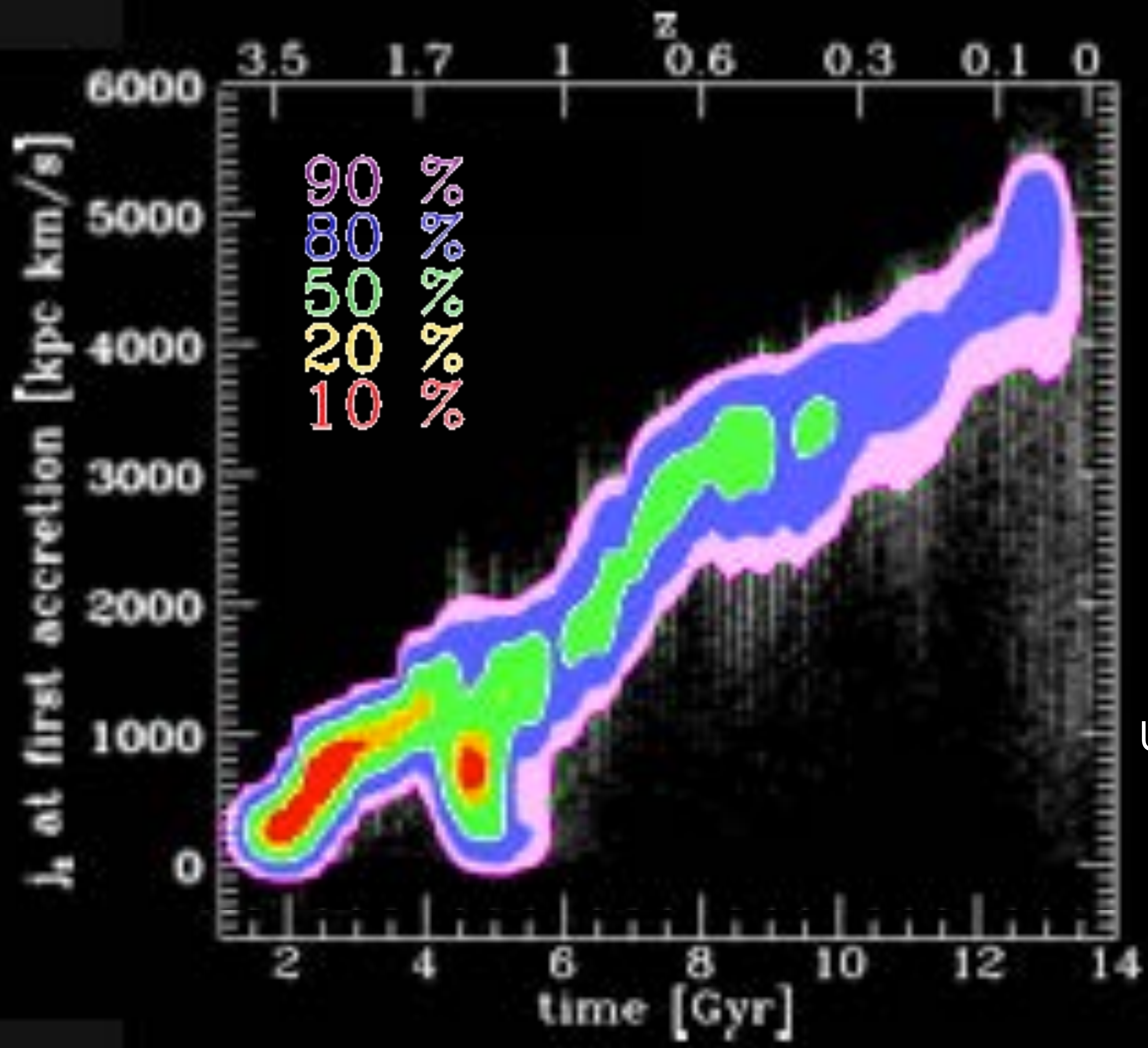
Spheroid Dominated at z=0



Disc Dominated at z=0

Sales et al. 2012

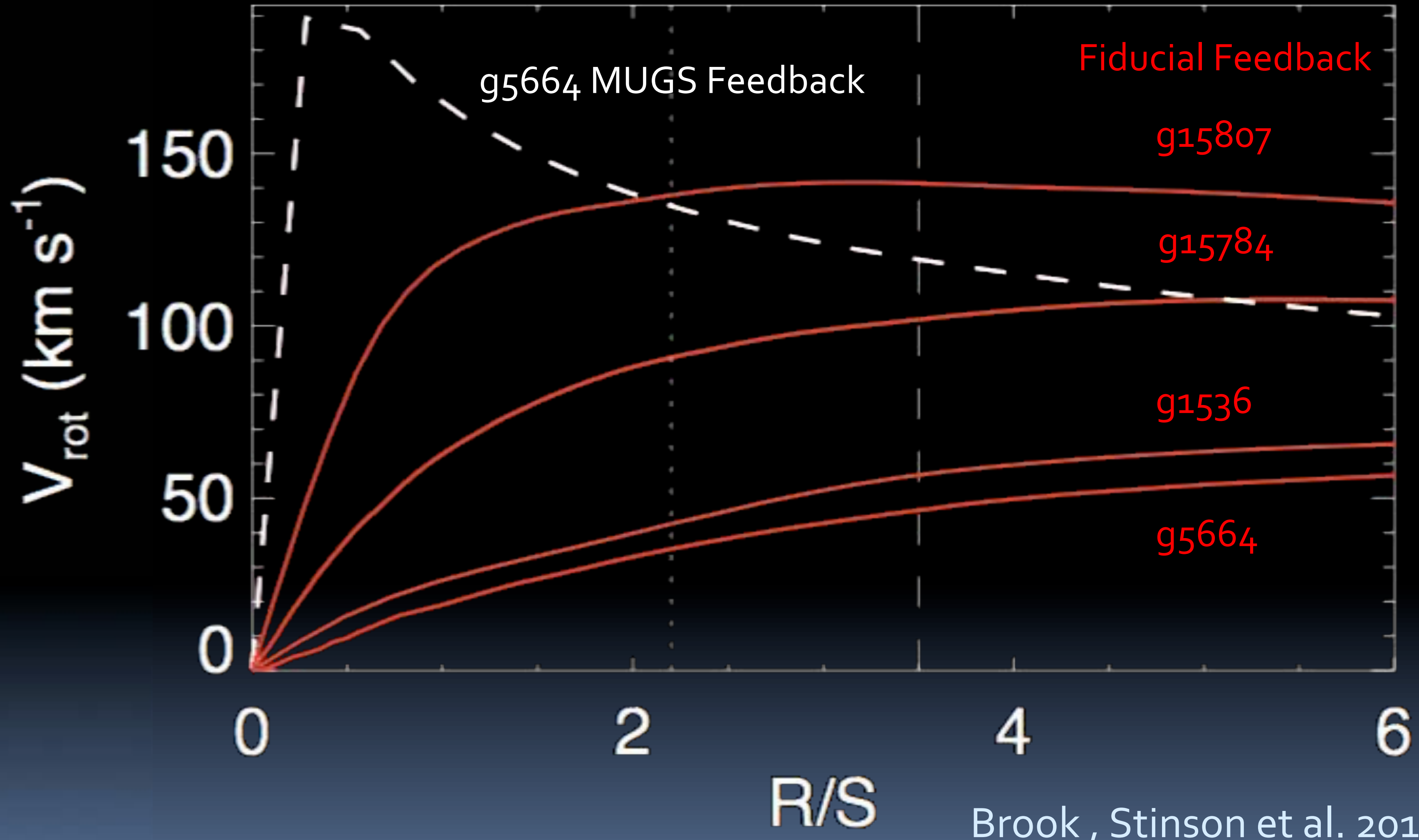
Increasing angular momentum



Ubler '14

Low angular momentum material is accreted first.

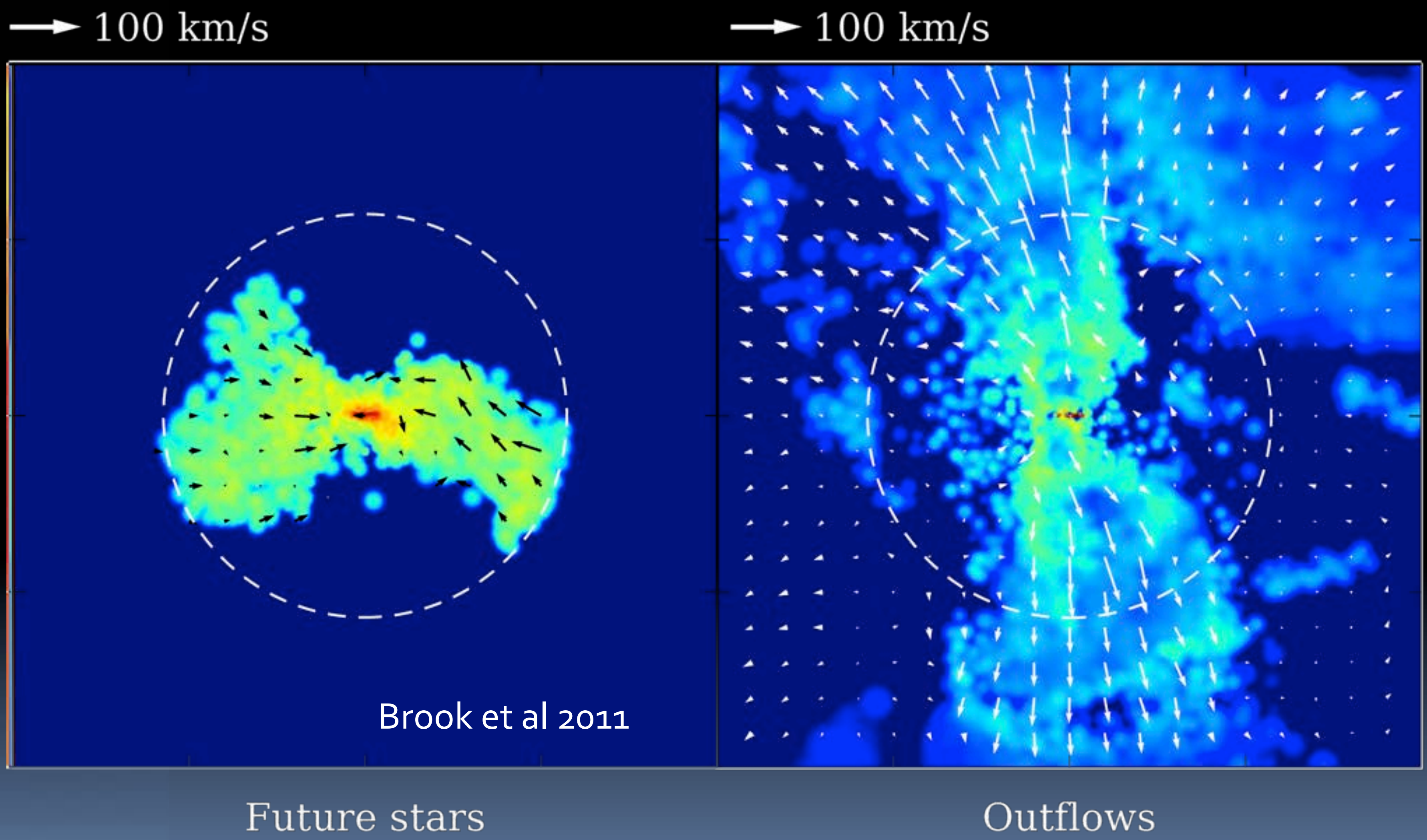
Simulated rotation curves



Brook , Stinson et al. 2012

Left: gas which will form stars by z=o. i.e. the inflowing gas that fuels star formation.

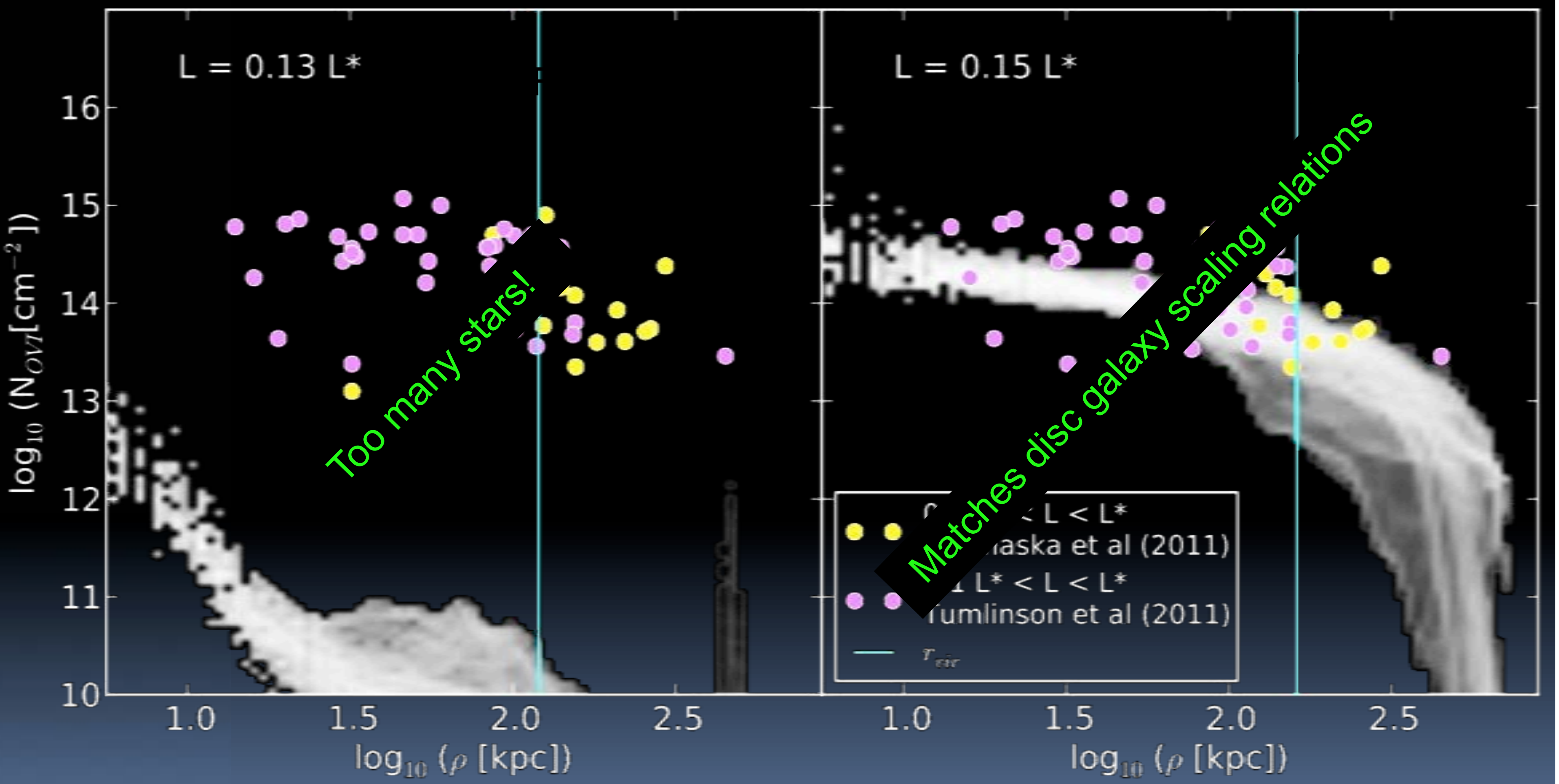
Right: gas outflows, i.e. gas which was in the inner star forming region but is not within the virial radius at z=o.



Inflows in the disk plane.

Outflows perpendicular to the disk the path of least resistance

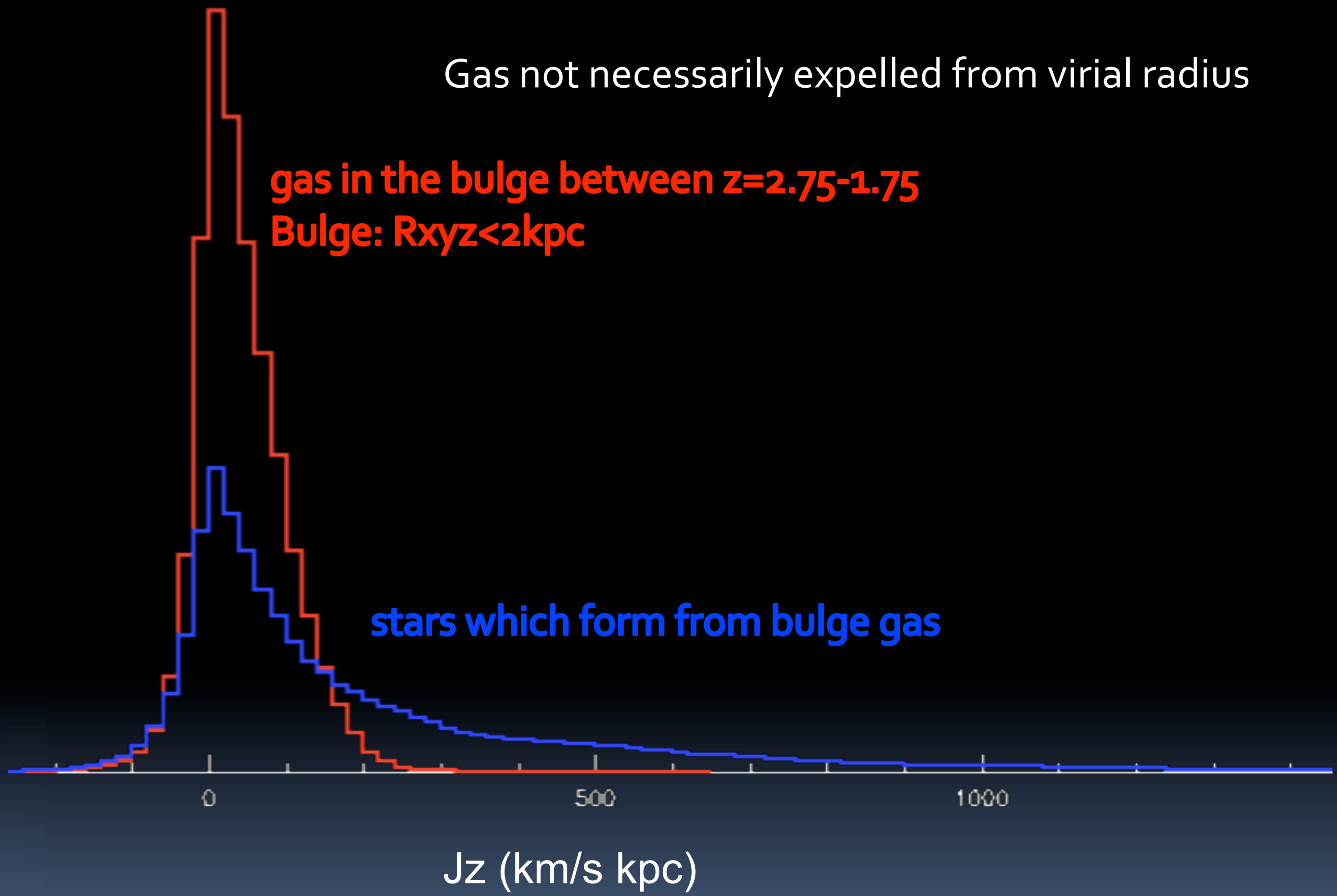
Comparing to the enriched CGM



Outflows can be traced by OVI
(see Kawata & Rauch 2007)

Stinson, Brook, Hennawi et al. 2012

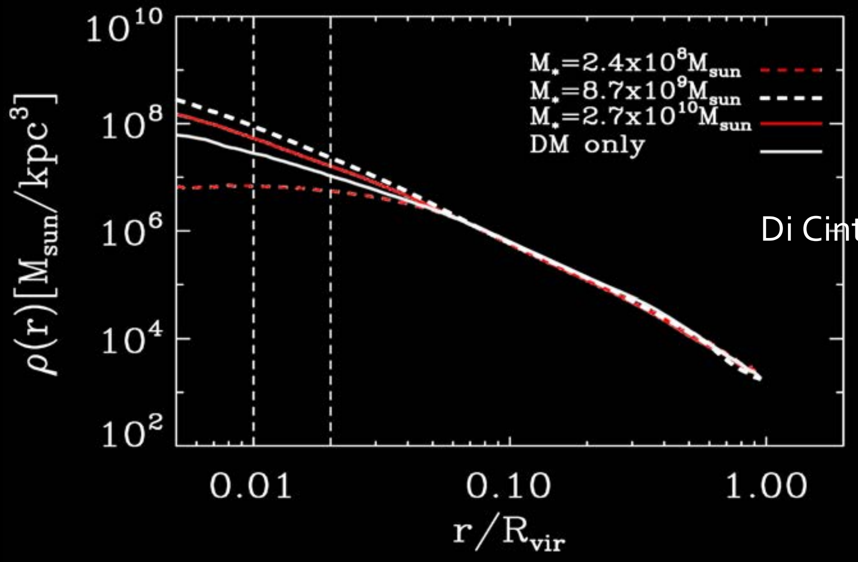
Ejection and Re-accretion



Brook, Stinson et al. 2012b Paper II

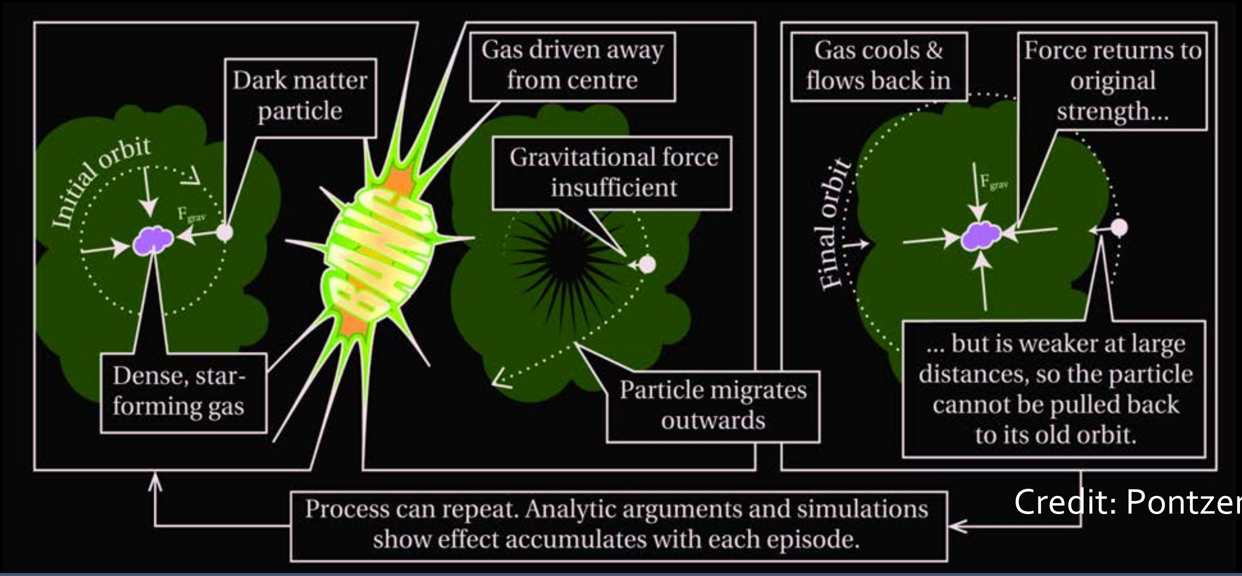
AM transfer Roškar et al. 2010

Core creation mechanism

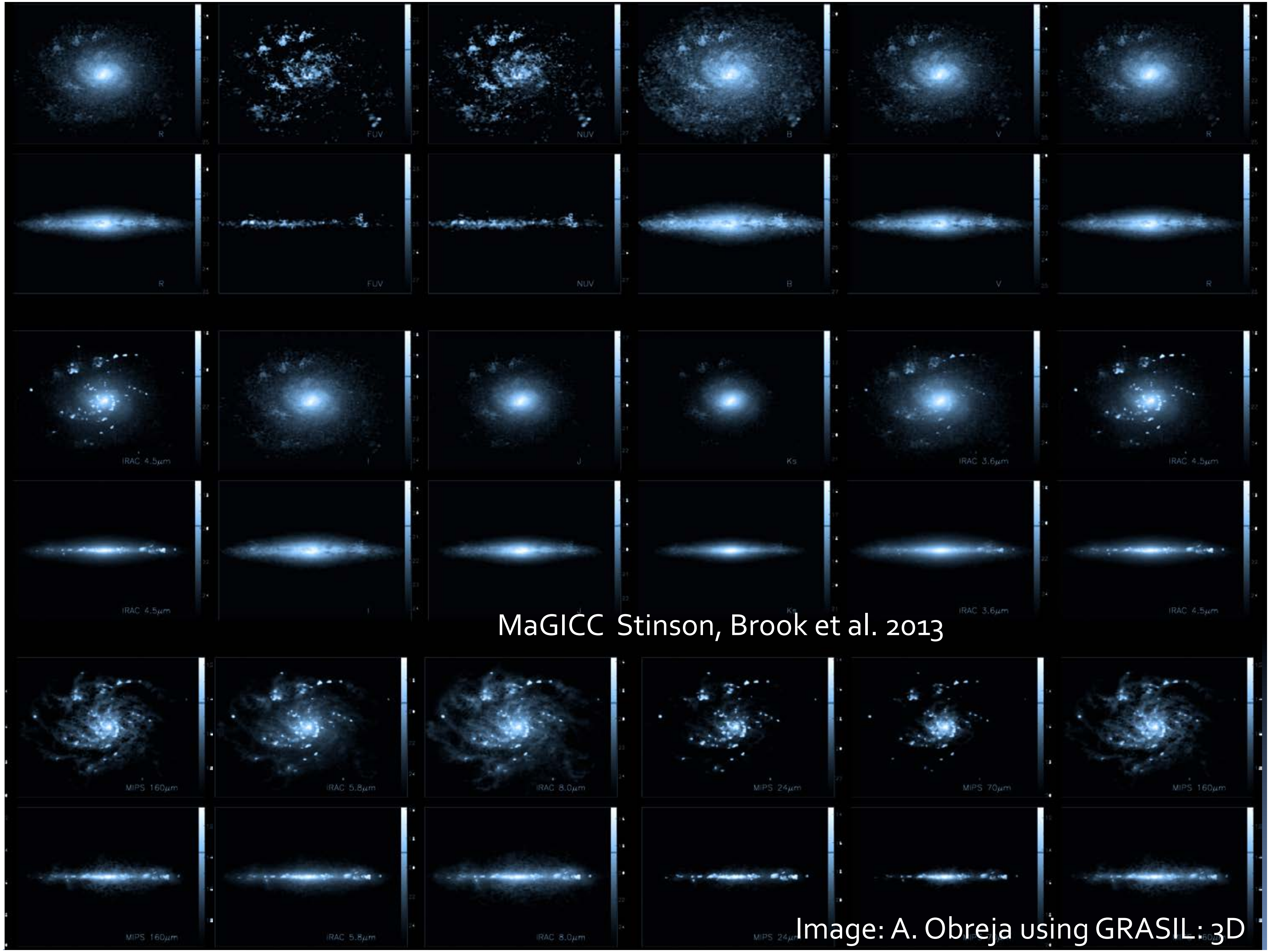


Di Cintio +14a

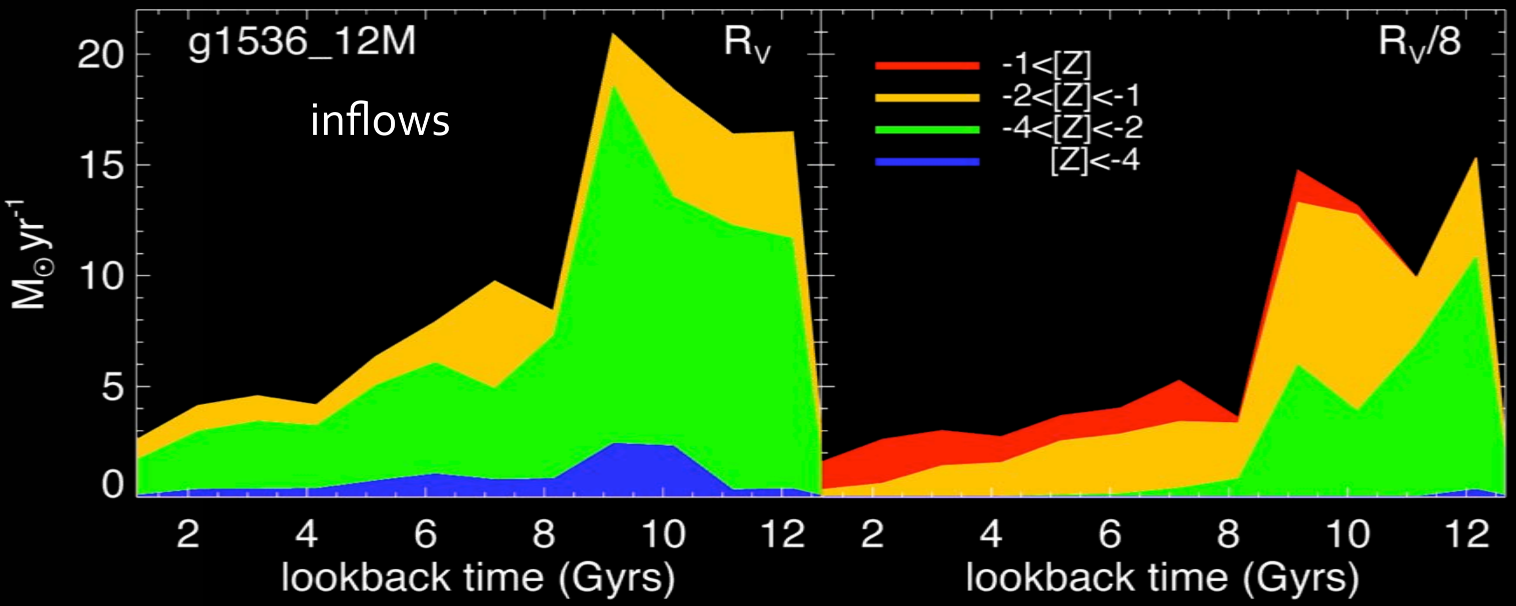
See also
Navarro +96
Read +06
Mashchenko +08,
Governato+12,
Pontzen & Governato 12



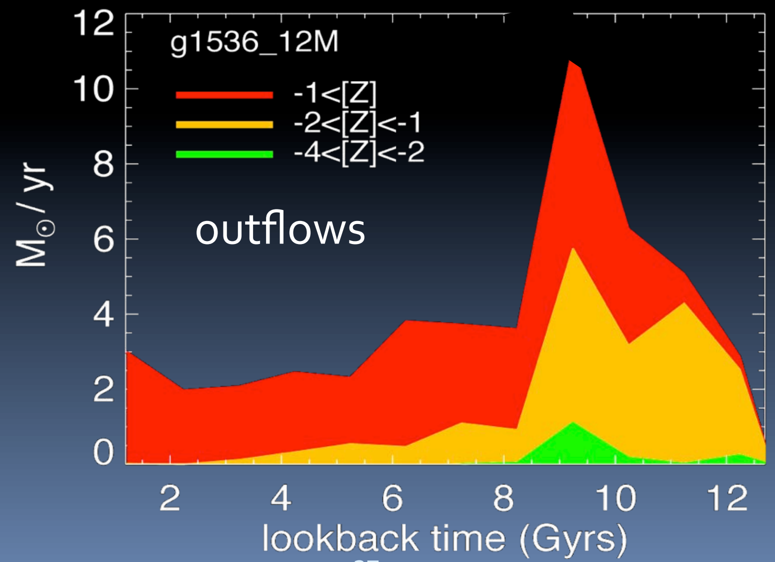
Credit: Pontzen & Governato 14


R
FUV
NUV
B
V
R
IRAC 4.5μm
I
J
Ks
IRAC 3.6μm
IRAC 4.5μm
MaGICC Stinson, Brook et al. 2013
MIPS 160μm
IRAC 5.8μm
IRAC 8.0μm
MIPS 24μm
MIPS 70μm
MIPS 160μm
Image: A. Obreja using GRASIL: 3D

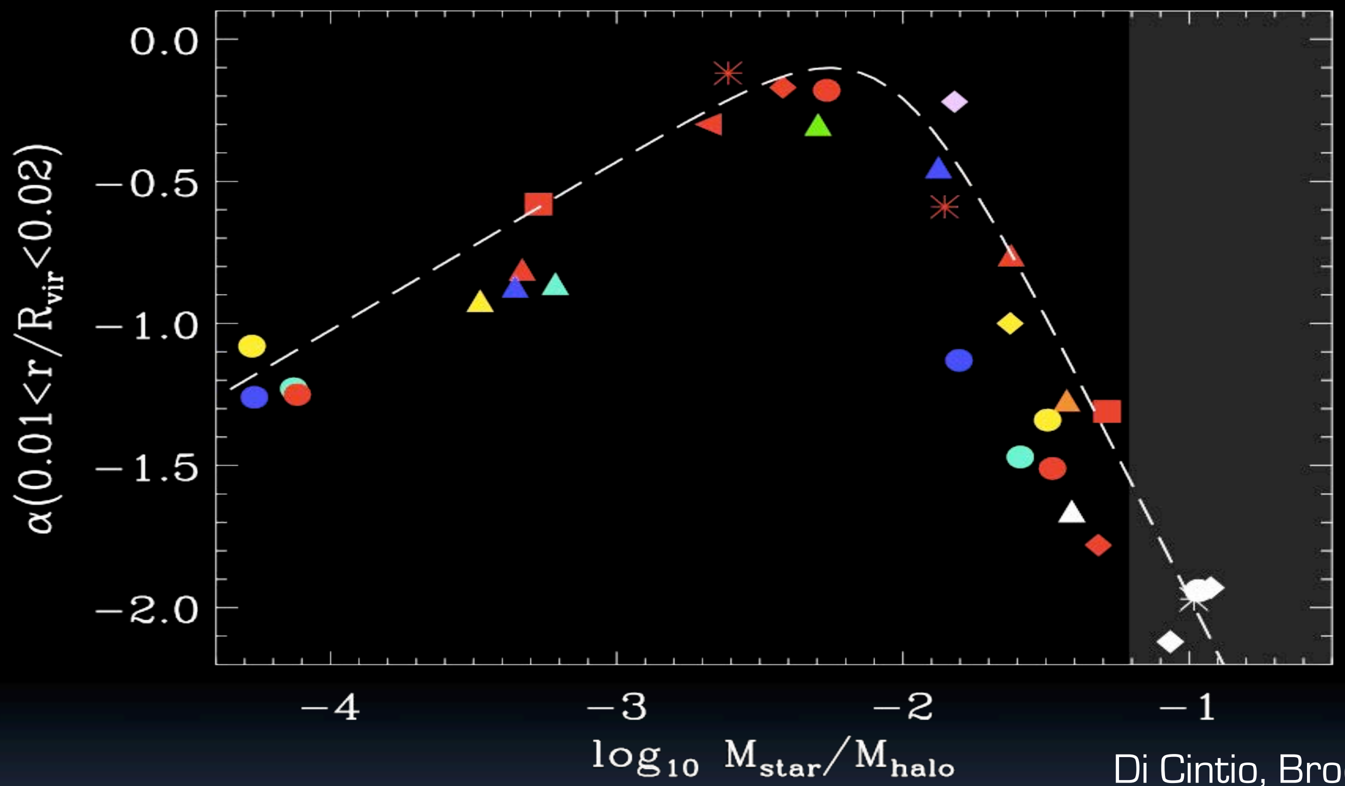
The Baryon Cycle in Simulated Galaxies



Brook et al. 2014

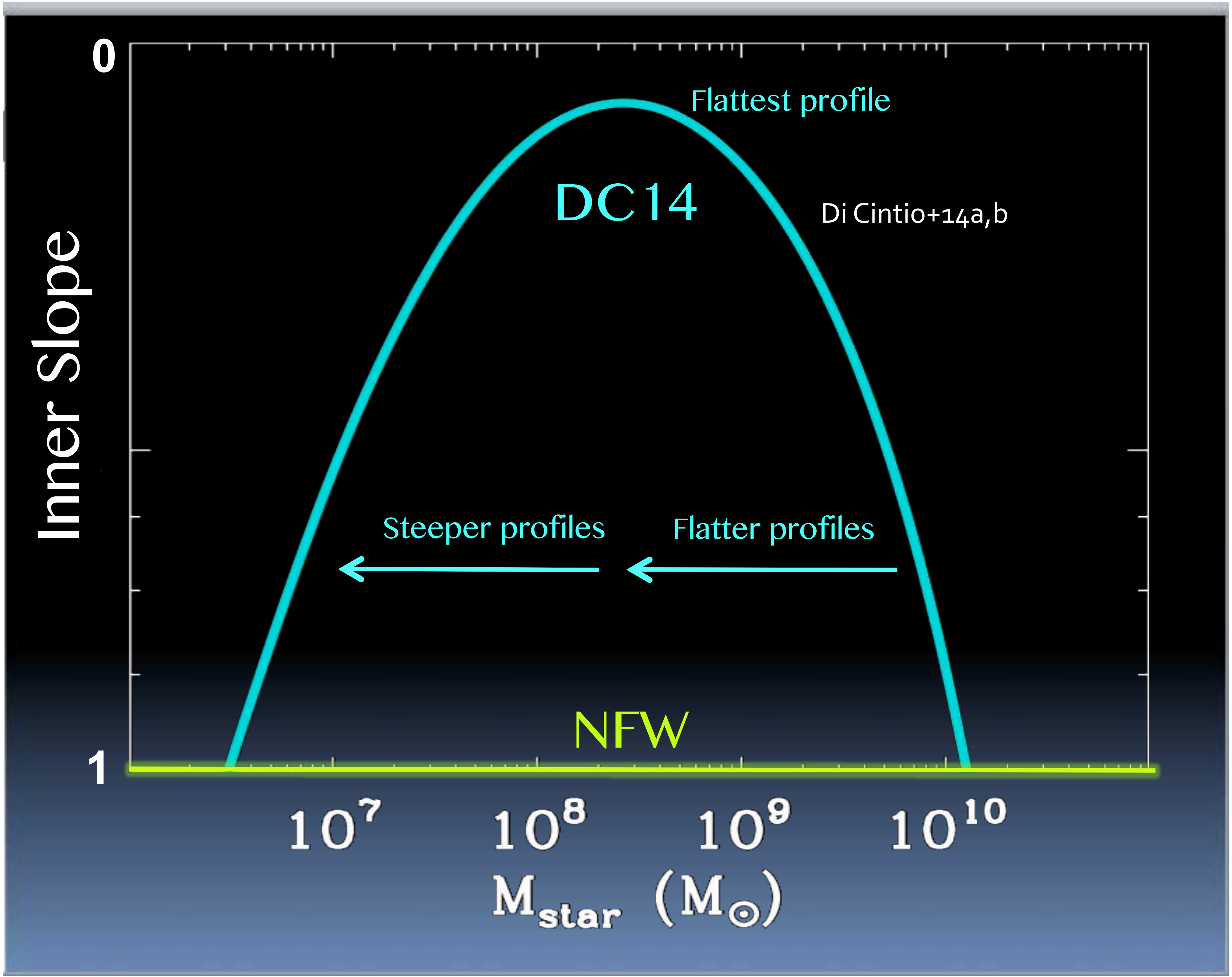


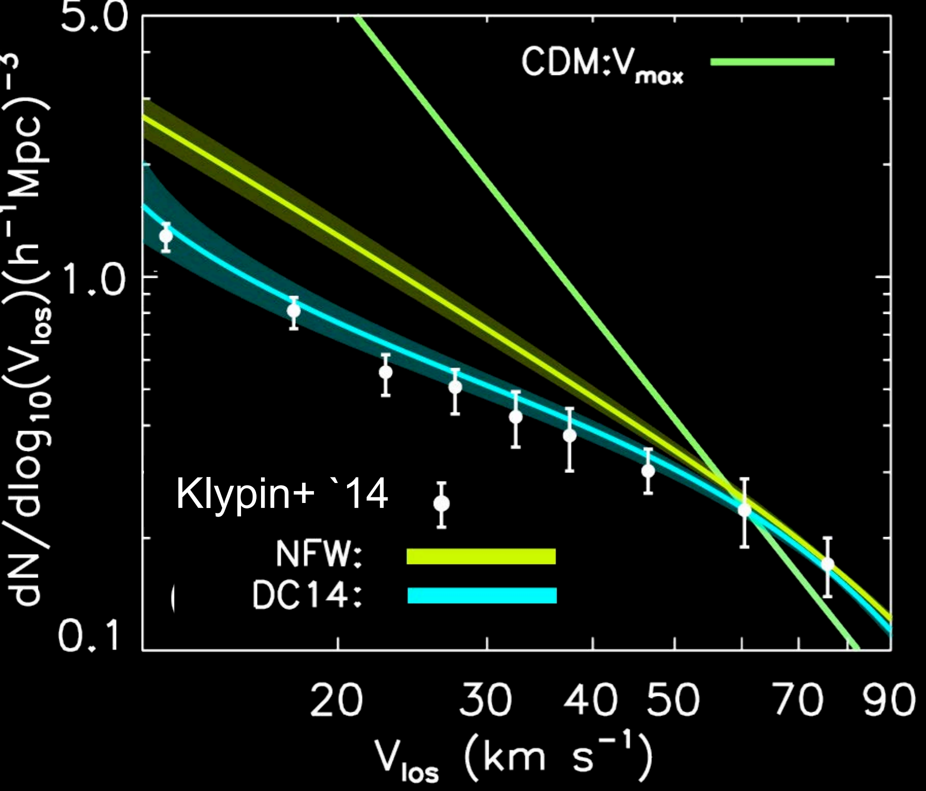
Inner slope dependence on $M_\star/M_{halo}$

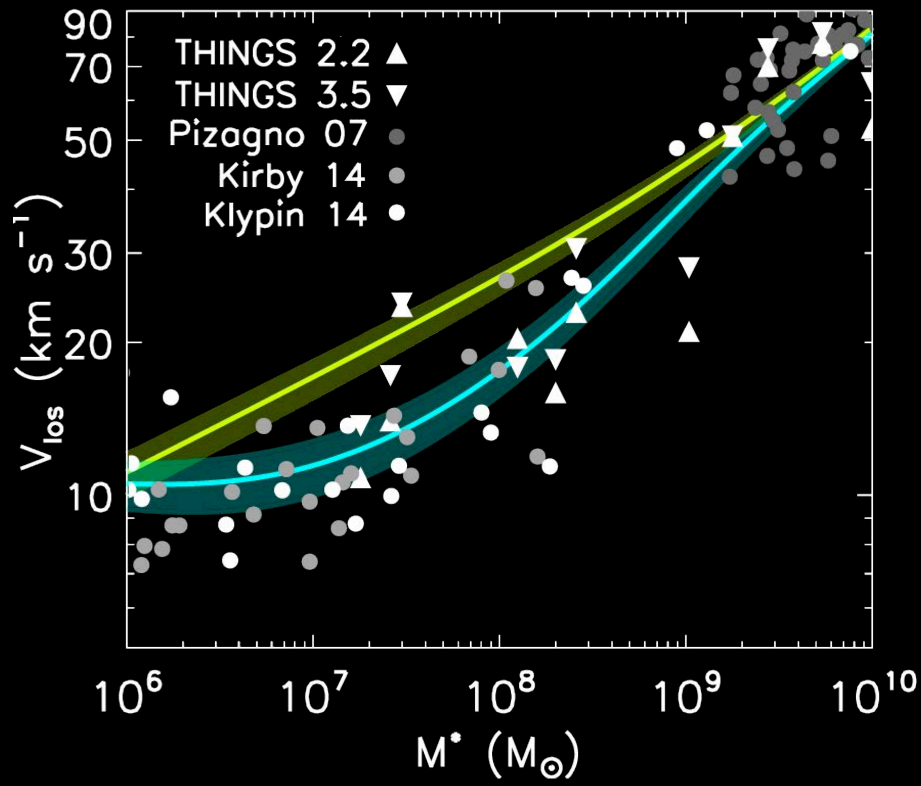


Di Cintio, Brook+14a

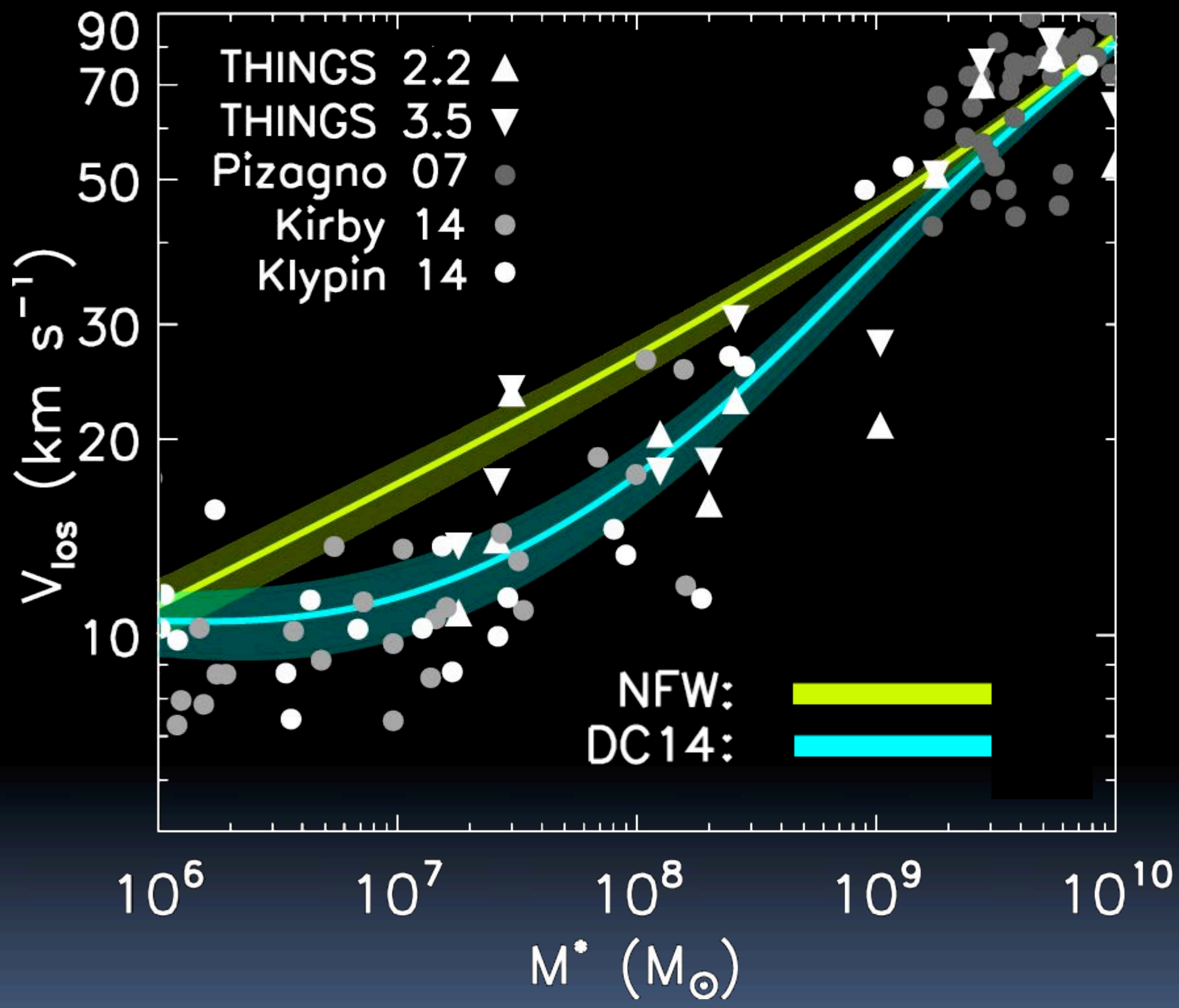
Dark matter profiles determined by two opposite effects:
energy from feedback vs increasing gravitational potential


0
1
Inner Slope
Flattest profile
DC14
Di Cintio+14a,b
Steeper profiles
Flatter profiles
NFW
10^7
10^8
10^9
10^{10}
M_{star} ($M_\odot$)





Brook & Di Cintio 2015



Brook & Di Cintio 2015

Conclusions

◆ Galaxy formation is intimately linked to the Cosmic Web at high redshift

◆ Imprints of the Cosmic Web can be found in the Milky Way structure and Galactic Archaeological studies

◆ Galaxy evolution at later times increasingly involves inflows outflows and recycling

◆ There is enough energy in the outflows to flatten the density profile of dark matter halos

◆ Signatures of halo flattening may be found within galaxy populations