

The Magneticum Simulations, from Galaxies to Galaxy Clusters

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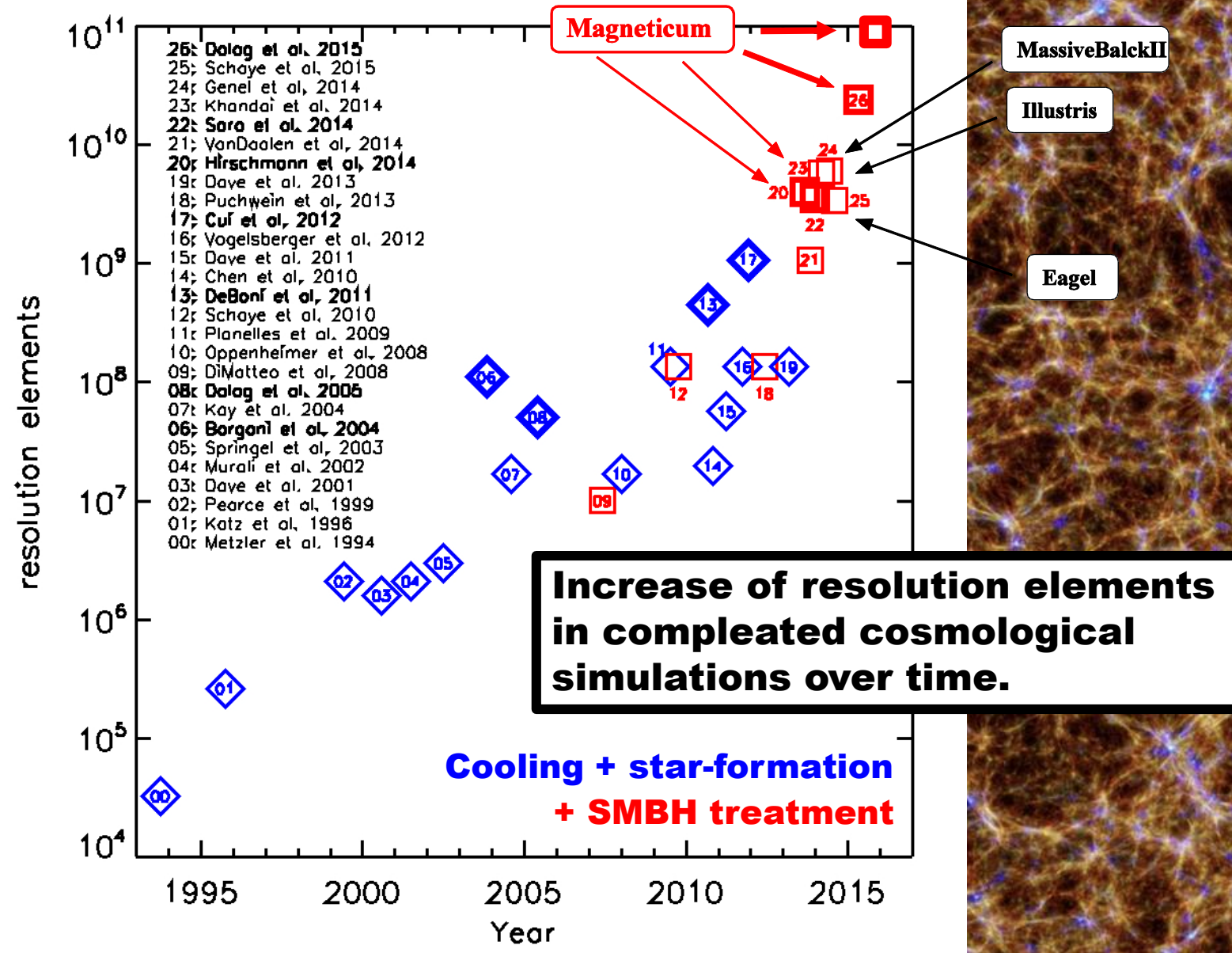
MAGNETICUM



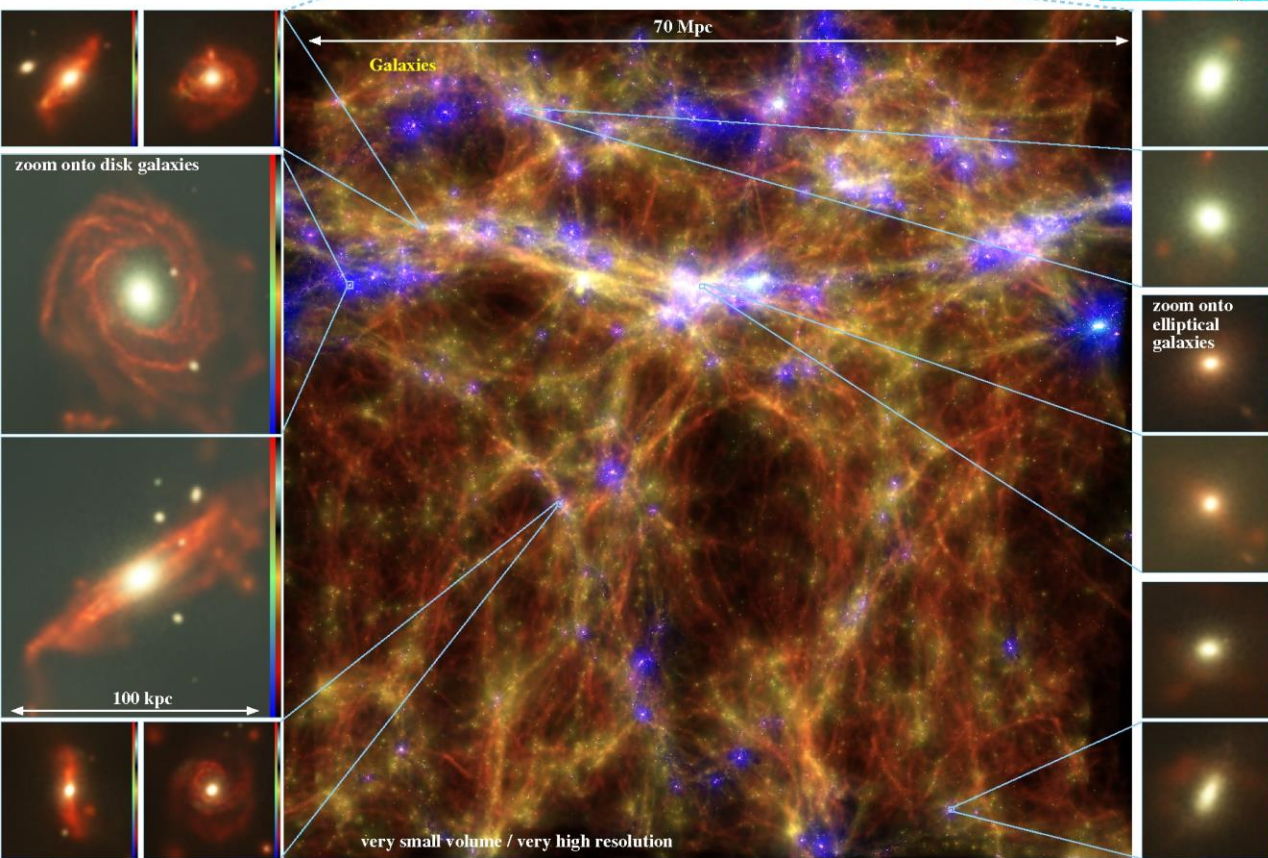
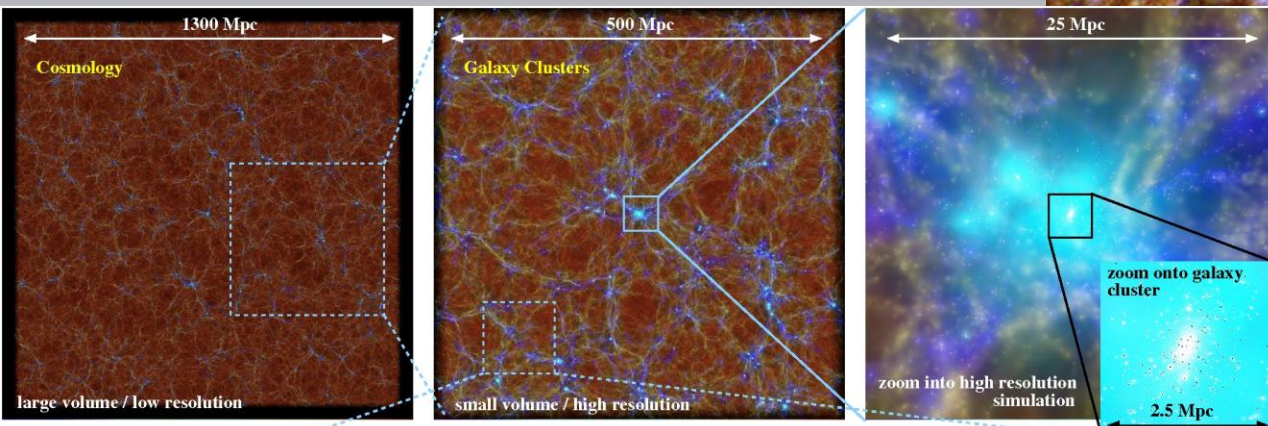
Remus, Saro, Steinborn, Teklu (USM), Hirschmann (AIP), Petkova (C2PAP), Ragagni (LRZ) ...



What we reached so far



The Simulations ...



Physics:

cooling+sfr+winds

Springel & Hernquist 2002/2003

Metals cooling

Wiersma et al. 2009

SNIa, SNII, AGB

Tornatore et al. 2003/2006

BH+AGN feedback

Springel & Di Matteo 2006

Fabjan et al. 2010

Hirschmann et al. 2014

Steinborn et al. 2015

Thermal conduction

1/20th Spitzer

Dolag et al. 2004

Numerics:

New Kernels: WC6

Dehnen et al. 2012

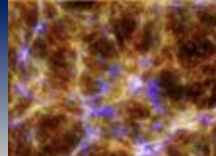
Low visc. scheme

mr/hr (time dep. alpha)

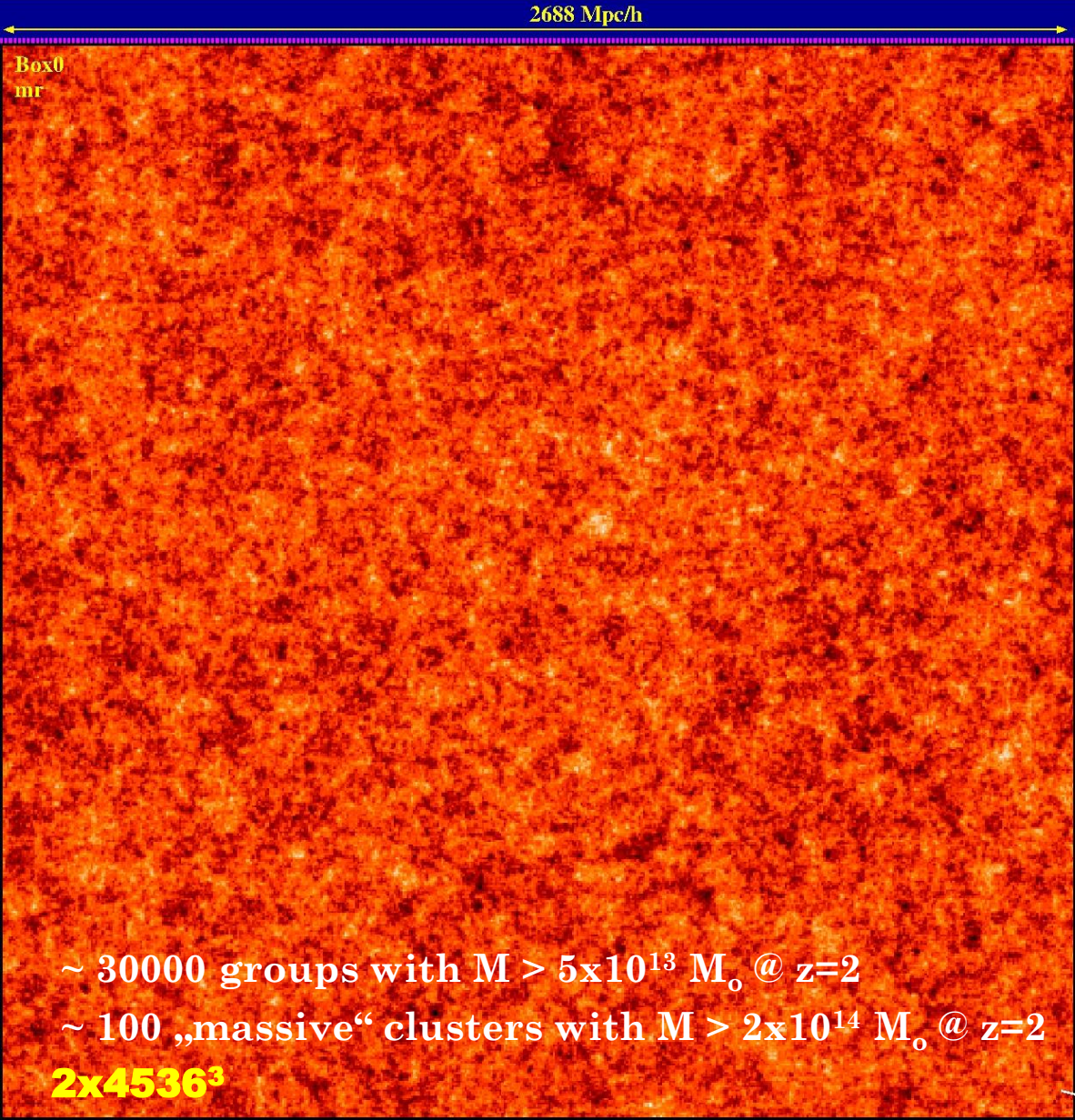
Dolag et al. 2005

uhr (high order grad.)

Beck et al. 2015

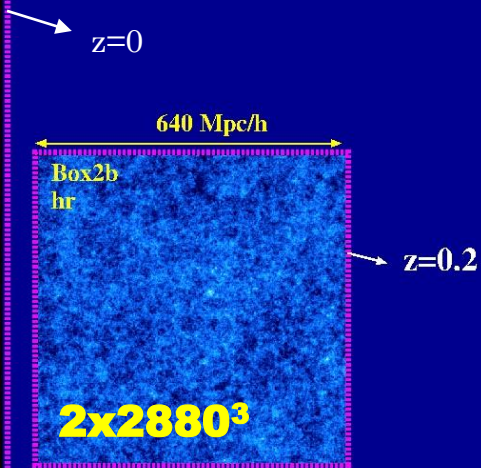


The Magneticum Simulations



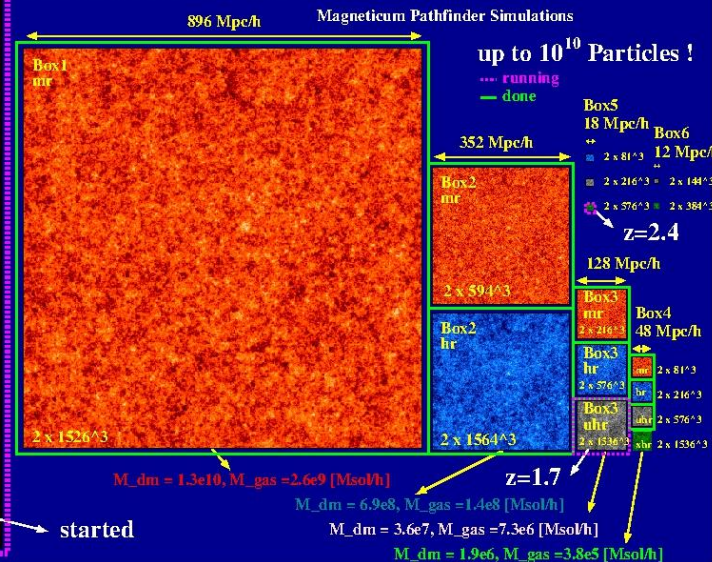
Magneticum Simulations

up to 10^{11} Particles !

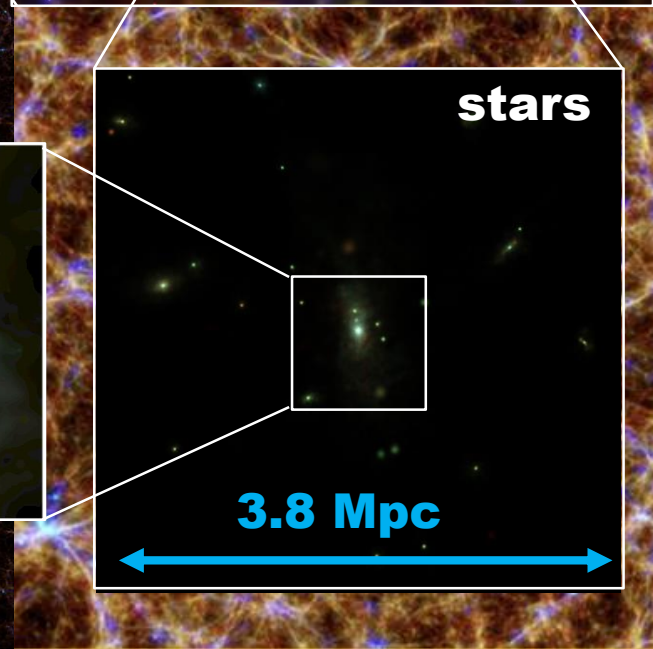
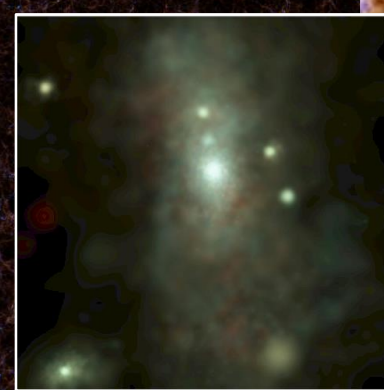
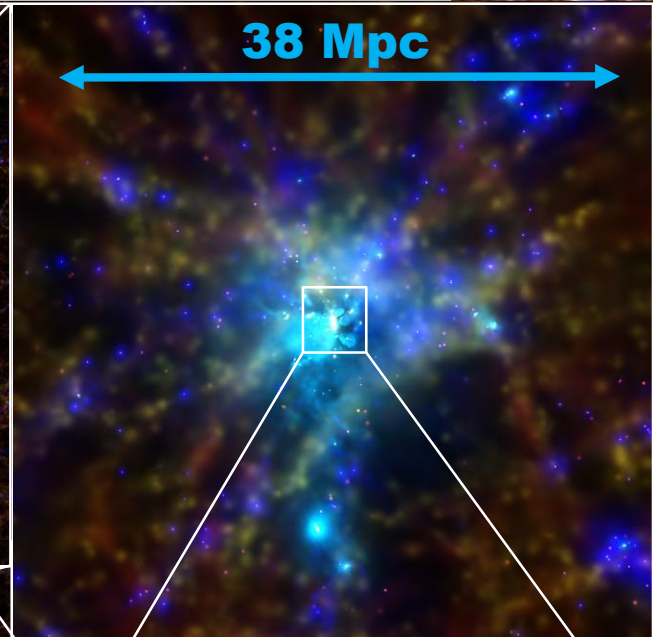
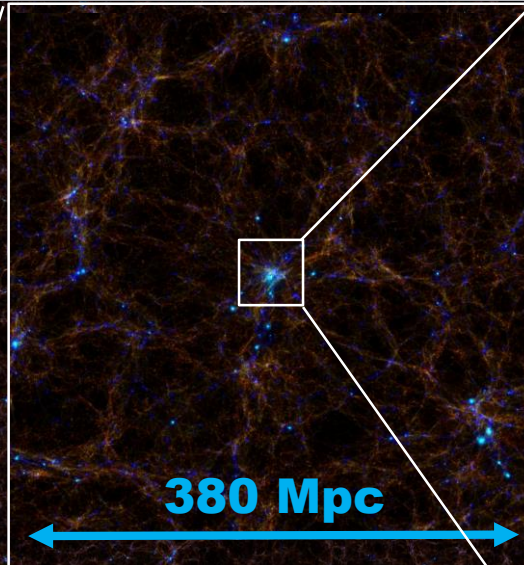
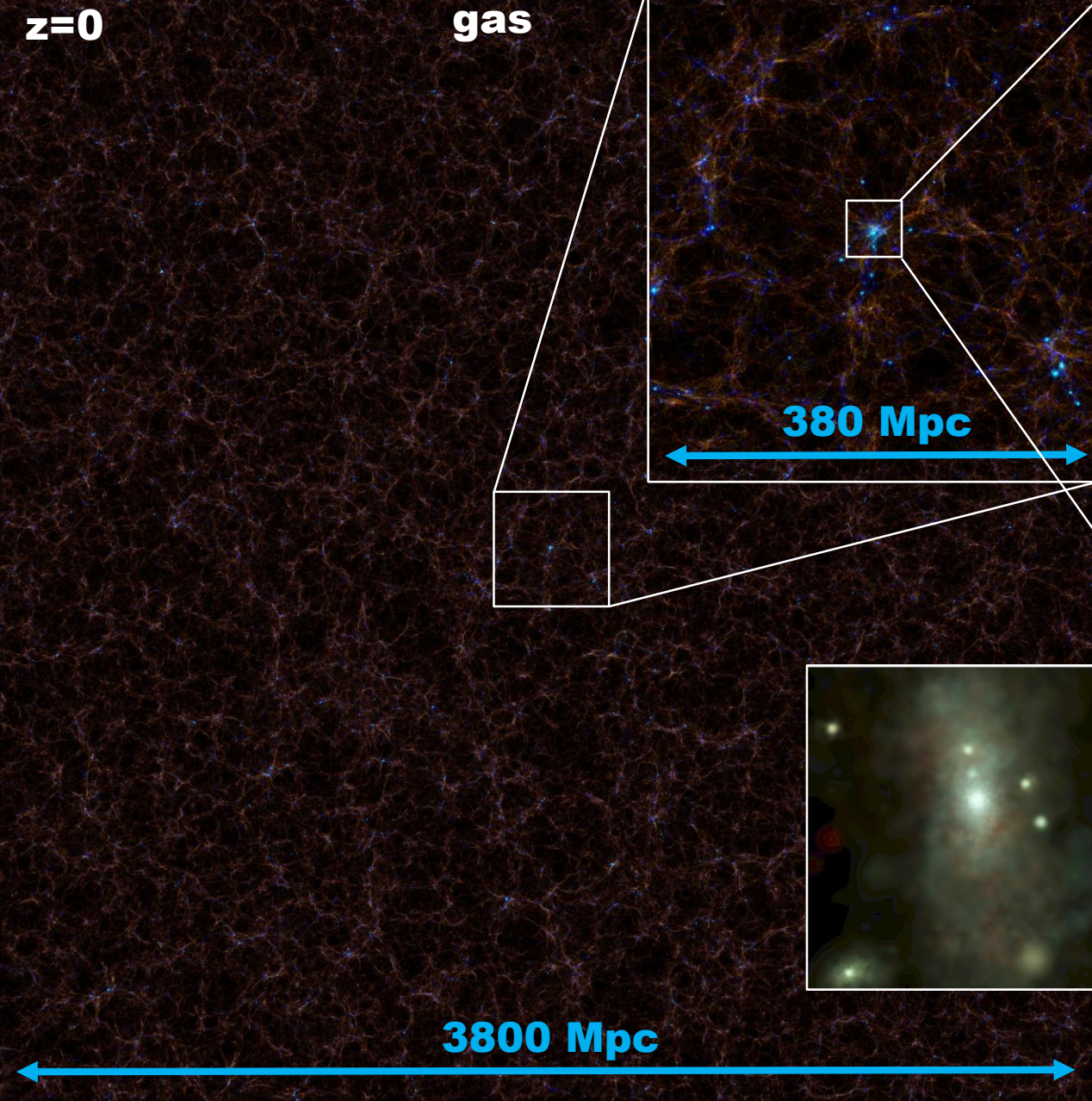
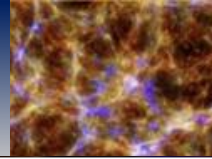


~ 30000 groups with $M > 5 \times 10^{13} M_{\odot}$ @ $z=2$
 ~ 100 „massive“ clusters with $M > 2 \times 10^{14} M_{\odot}$ @ $z=2$

2×4536^3



Largest Simulation (Box0/mr)

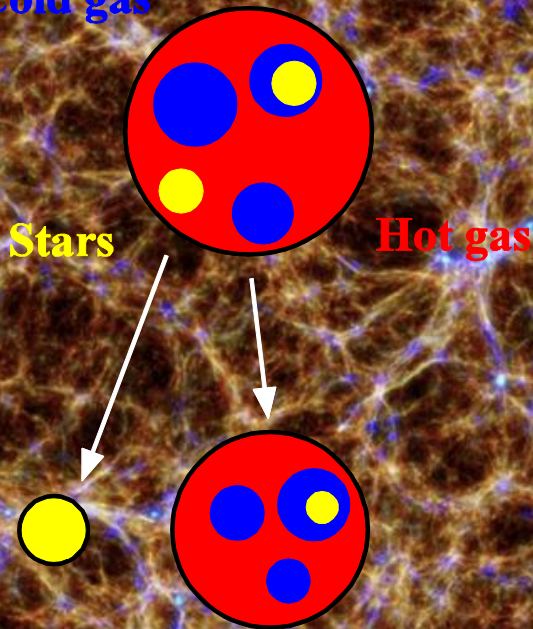


Sub-resolution star-formation:

Multi phase model (sub-scale)

Springel & Hernquist 2002

Cold gas



Star formation

$$\frac{d\rho_{\star}}{dt} = (1 - \beta) \frac{\rho_c}{t_{\star}}$$

supernova mass fraction

star formation timescale

Cloud evaporation

$$\left. \frac{d\rho_h}{dt} \right|_{\text{evap}} = A\beta \frac{\rho_c}{t_{\star}}$$

cloud evaporation parameter

Growth of clouds

$$\left. \frac{d\rho_c}{dt} \right|_{\text{TF}} = - \left. \frac{d\rho_h}{dt} \right|_{\text{TF}} = \frac{\Lambda_{\text{net}}(\rho_h, u_h)}{u_h - u_c}$$

cooling function

Chemical enrichment:

Stellar evolution model (sub-scale)

Tornatore et al. 2003/2007

Energy: SNIa, SNII
Metals: SNIa, SNII, AGB winds
 H, He, C, Ca, O, N, Ne, Mg
 S, Si, Fe, Na, Al, Ar, Ni

fraction of stars in binary systems

star-formation rate

SNIa rate:

$$R_{\text{SNIa}}(t) = A \int_{M_{\text{B,inf}}}^{M_{\text{B,sup}}} \phi(m_{\text{B}}) \int_{\mu_{\text{m}}}^{\mu_{\text{M}}} f(\mu) \psi(t - \tau_{m_2}) d\mu dm_{\text{B}}$$

SNII and AGB rate:

mass range of SN1a binary systems (0.8-8Msol)

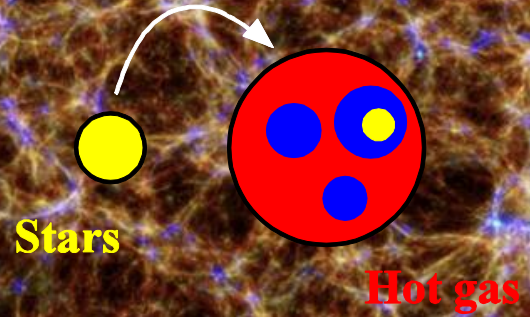
$$R_{\text{SNII|ILMS}}(t) = \phi(m(t)) \times \left(-\frac{dm(t)}{dt} \right)$$

Initial mass function (IMF):

$$\phi(m) = dN/d \log m$$

Life-time of stars

$$\tau(m) = \begin{cases} 10^{[(1.34 - \sqrt{1.79 - 0.22(7.76 - \log(m))})/0.11] - 9} & \text{for } m \leq 6.6 M_{\odot} \\ 1.2m^{-1.85} + 0.003 & \text{otherwise.} \end{cases}$$



IMF:
 Salpeter, Kroupa, Chabrier,
 Arimoto & Yoshii

Life-time:
 Maeder & Meynet 1989
 Padovani & Matteucci 1993

Stellar yields:
AGB: Groenewegen, Karakas
SN1a: Thielemann
SNII: Woosly & Weaver
 Romano, Kobayashi, ...

Sub-resolution SMBH-formation:

Black Hole model (sub-scale)

Springel & Di Matteo 2006

Seeding

Constant seeding
Seeding on m -sigma

Accretion on BH

α -Bondi (Springel & Di Matteo 06)
 β -Bondi (Booth & Schaye 09)
cold/hot (Bachmann et al. 14)
....

Feedback

Thermal (Springel & Di Matteo 06)
Bubbles (Sijacki et al. 07)
Mass dependent (Bachmann et al. 14)
....

Merging

Instant merging
Based on velocity
....

Growth of Black Hole

$$\dot{M}_B = \alpha \times 4\pi R_B^2 \rho c_s \simeq \frac{4\pi\alpha G^2 M_\bullet^2 \rho}{(c_s^2 + v^2)^{3/2}}$$

gas density

sound speed

$$\dot{M}_\bullet = \min(\dot{M}_B, \dot{M}_{\text{Edd}})$$

Feedback by Black Holes

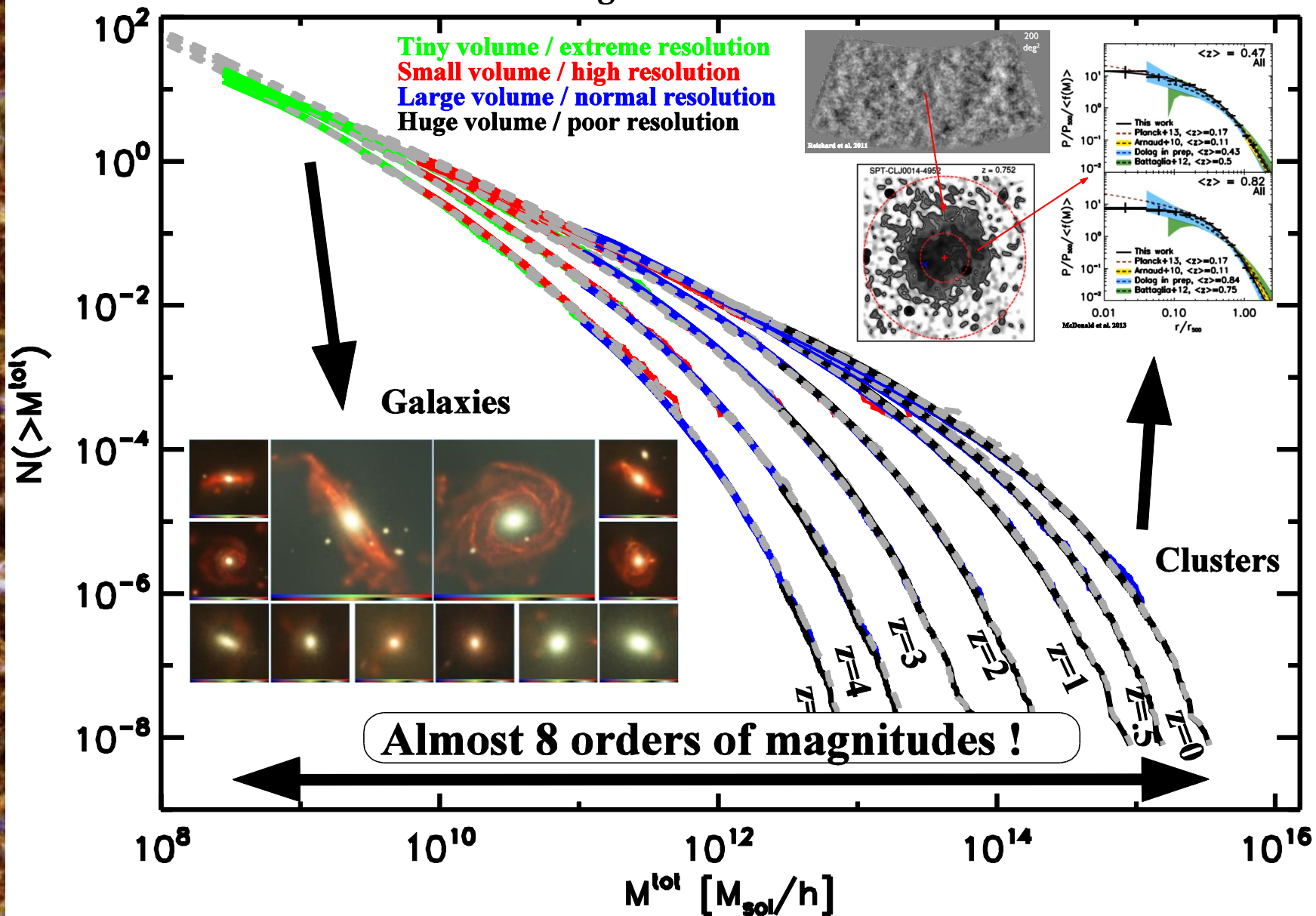
$$L_{\text{bol}} = 0.1 \times \dot{M}_\bullet c^2$$

$$\dot{E}_{\text{feedback}} = f \times L_{\text{bol}}$$

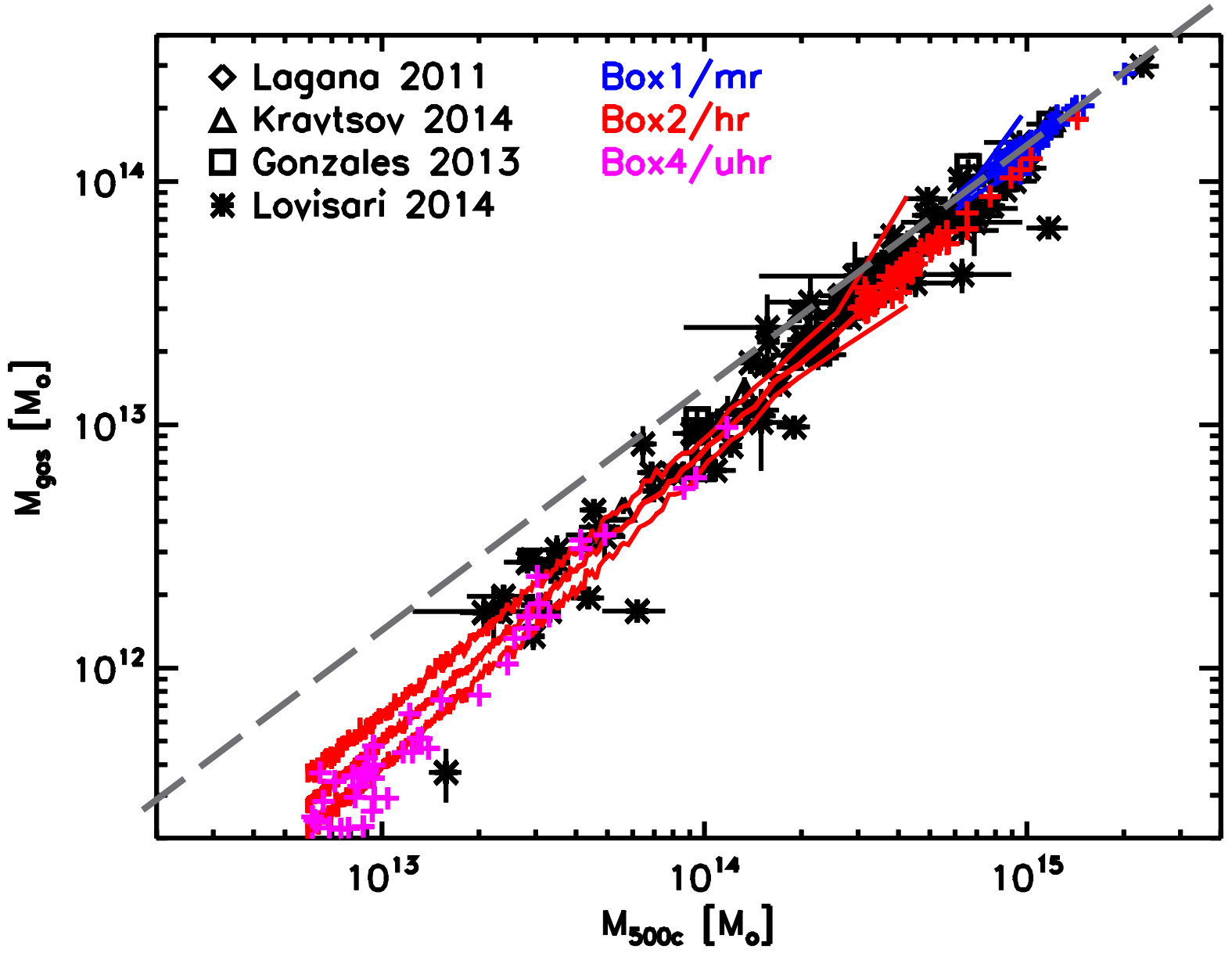
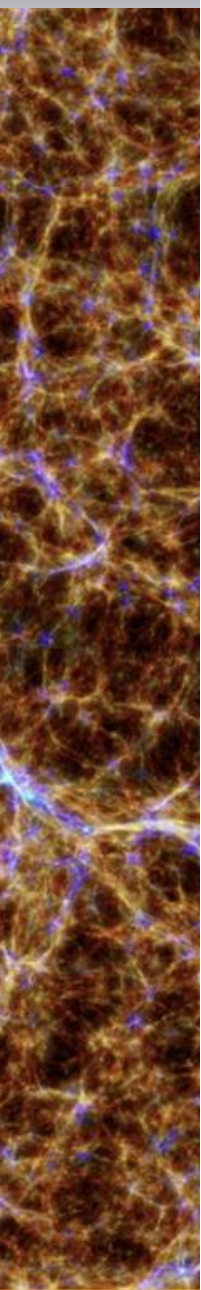
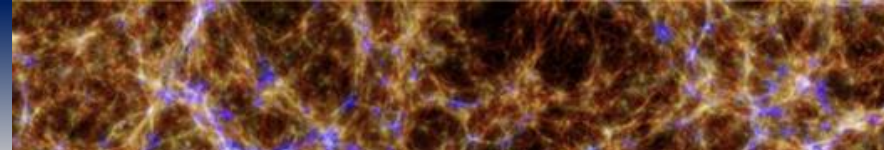
efficiency

What can we do ...

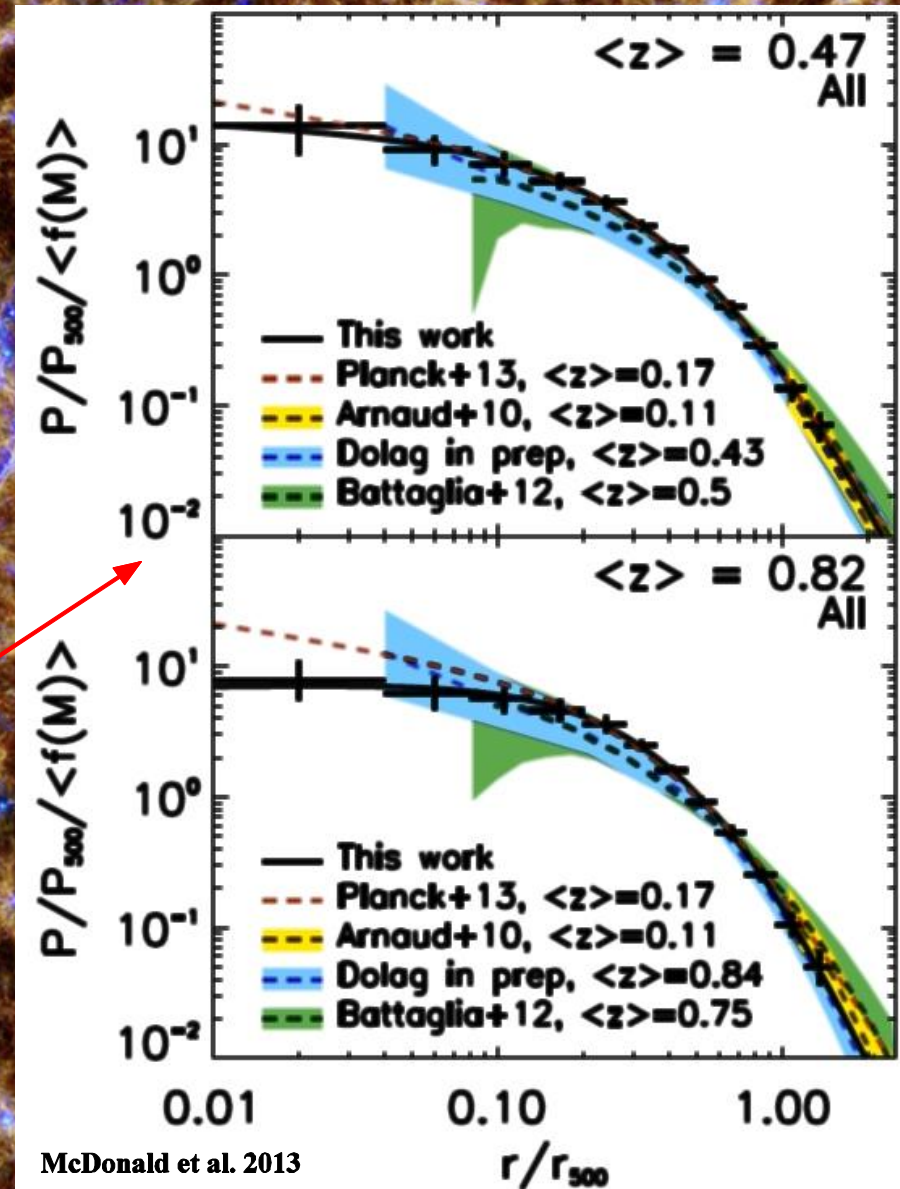
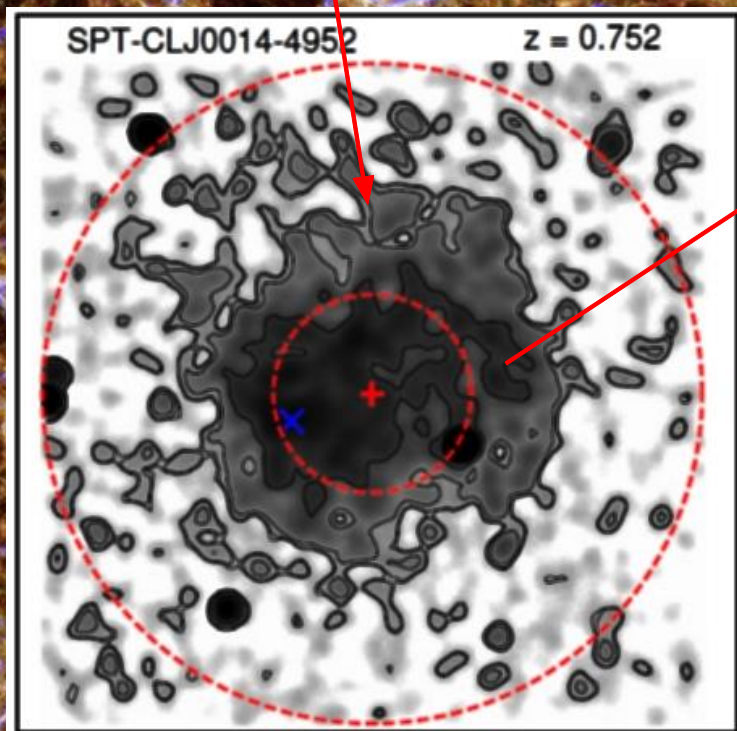
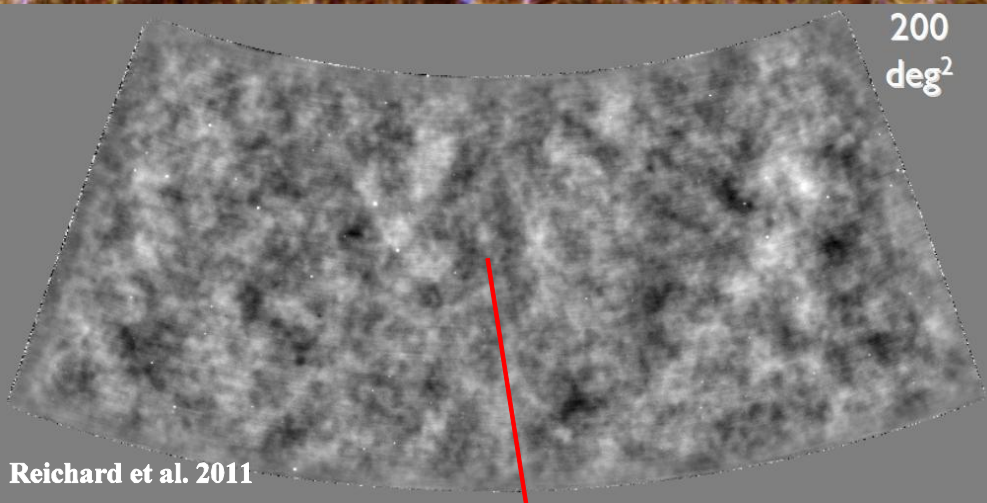
Combining different Simulations



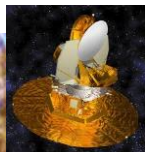
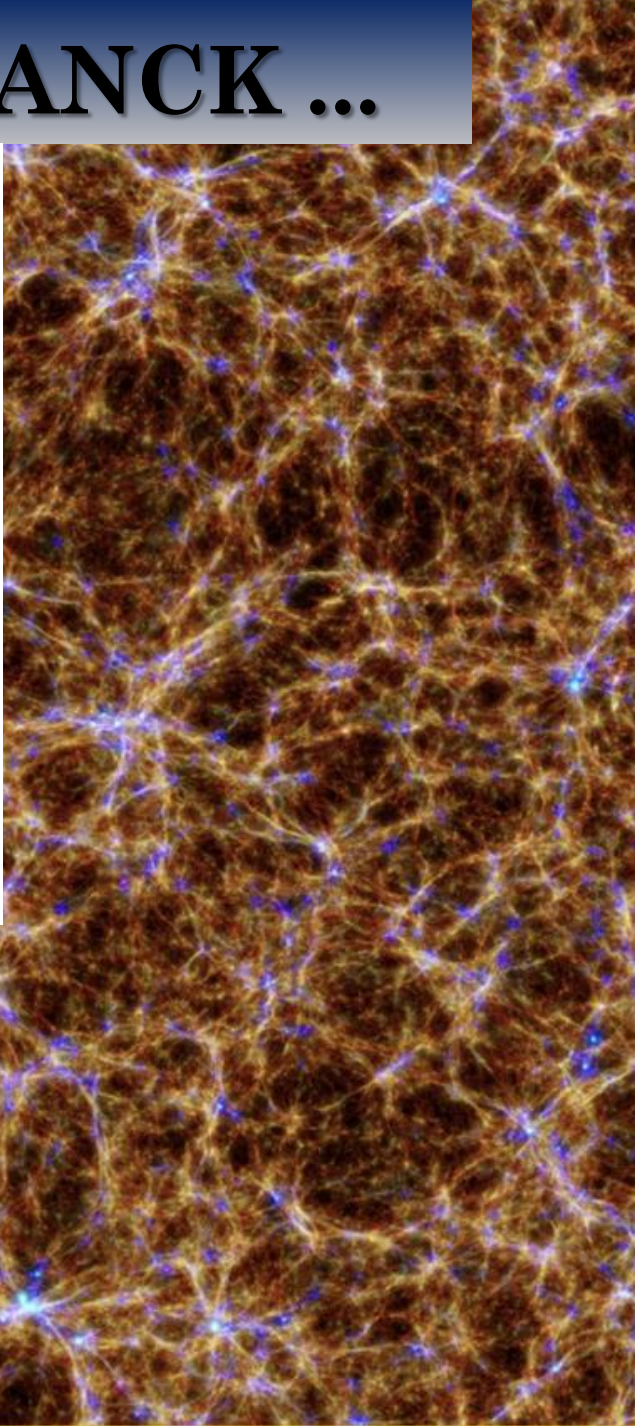
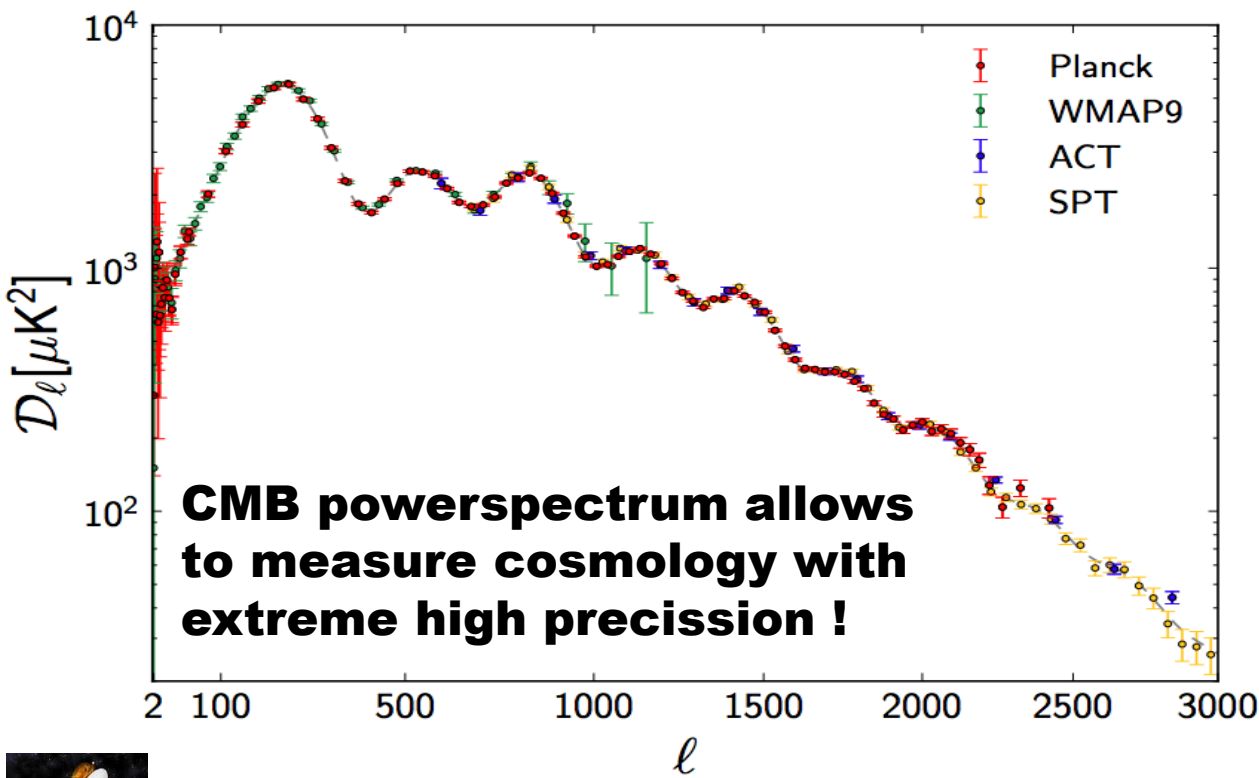
Gas mass of halos



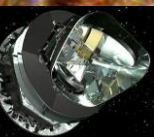
Pressure profiles of clusters



Cluster Cosmology and PLANCK ...



WMAP →

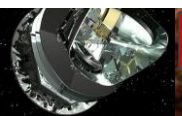
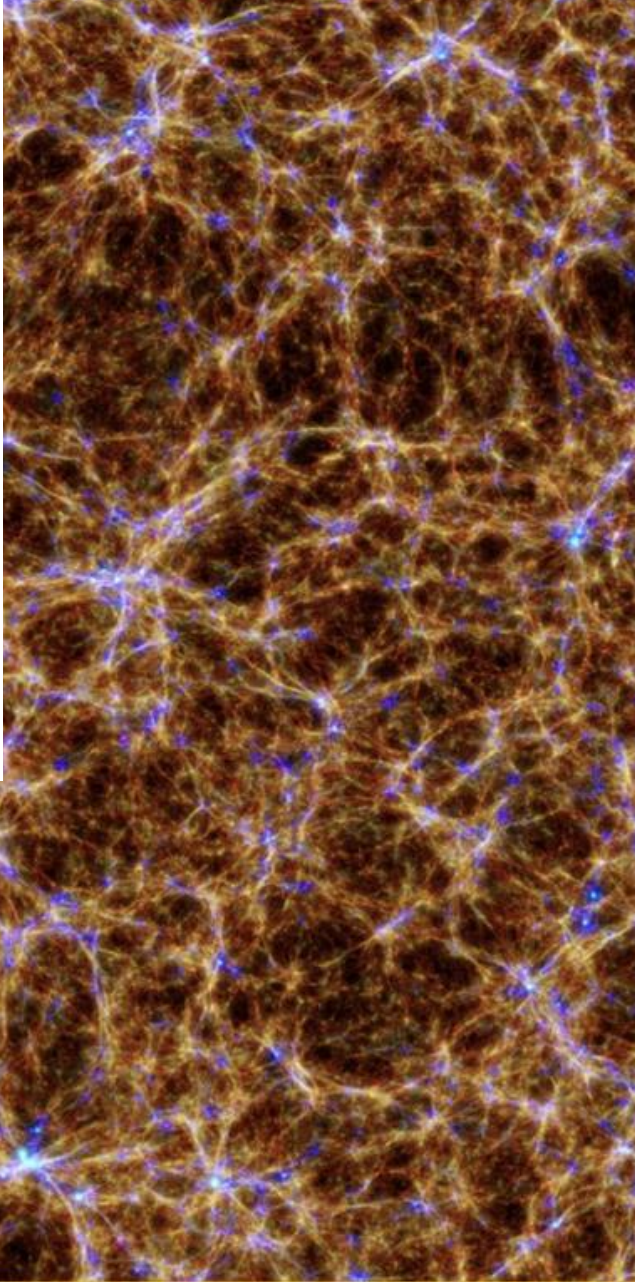
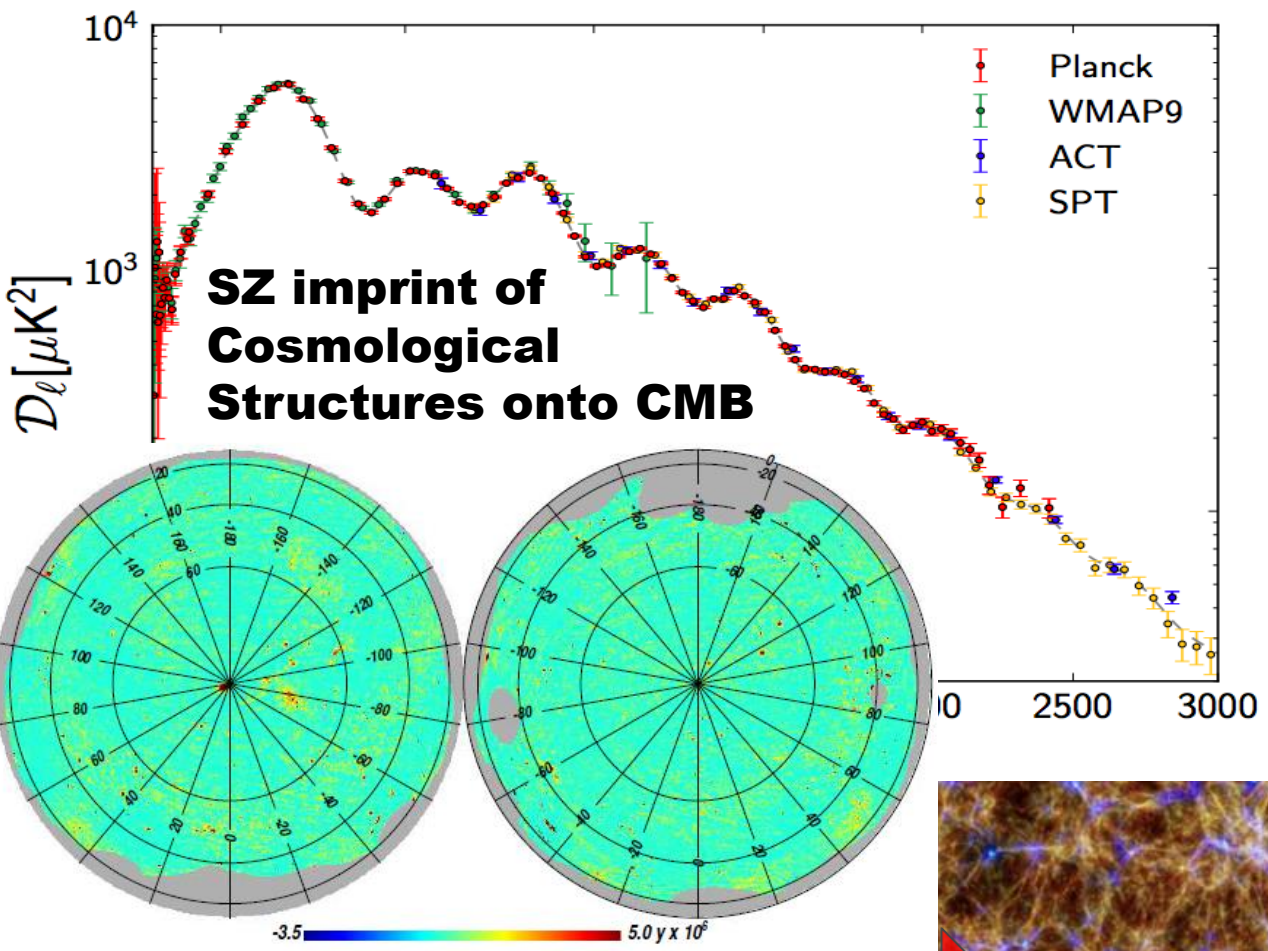


Planck →



SPT und ACT →

Cluster Cosmology and PLANCK ...

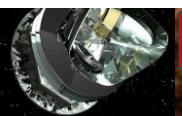
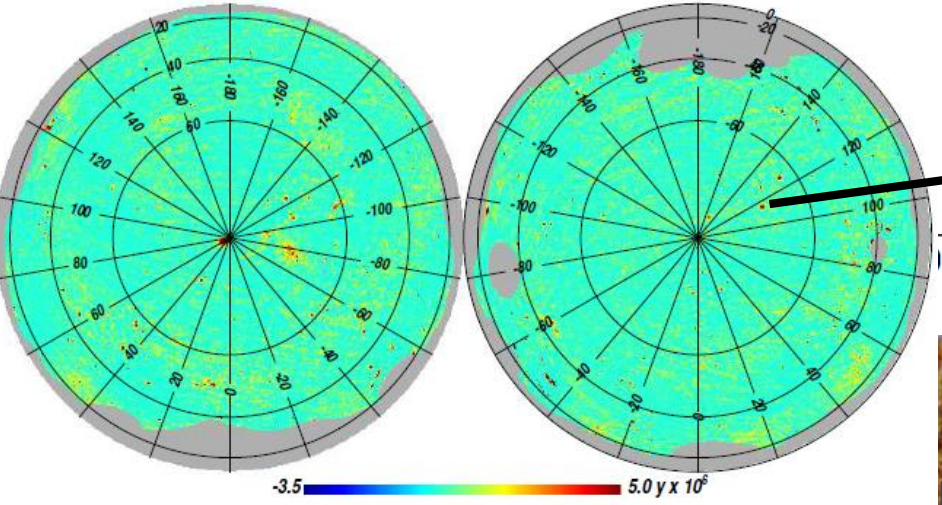
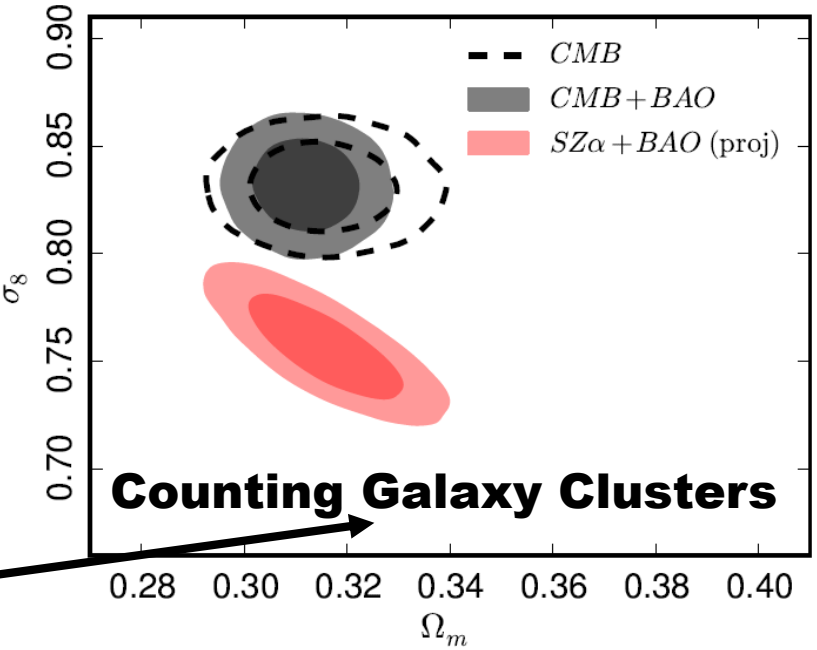
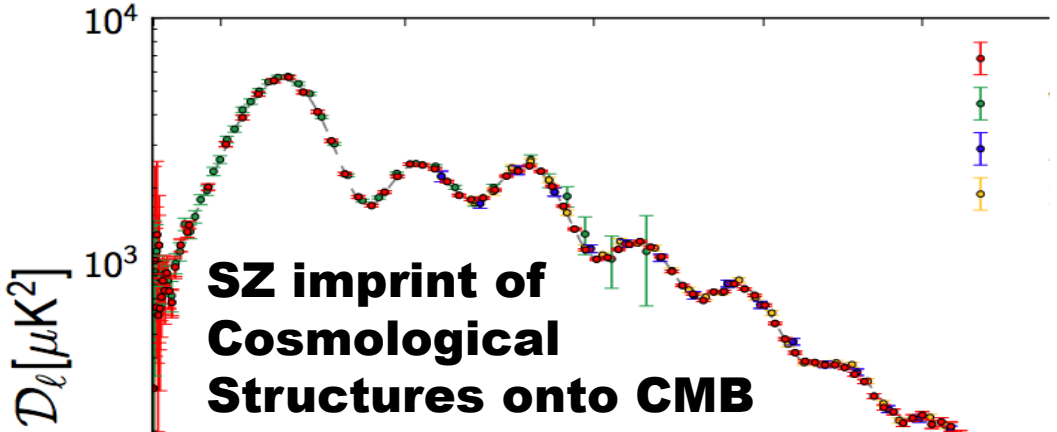


Planck



SPT und ACT

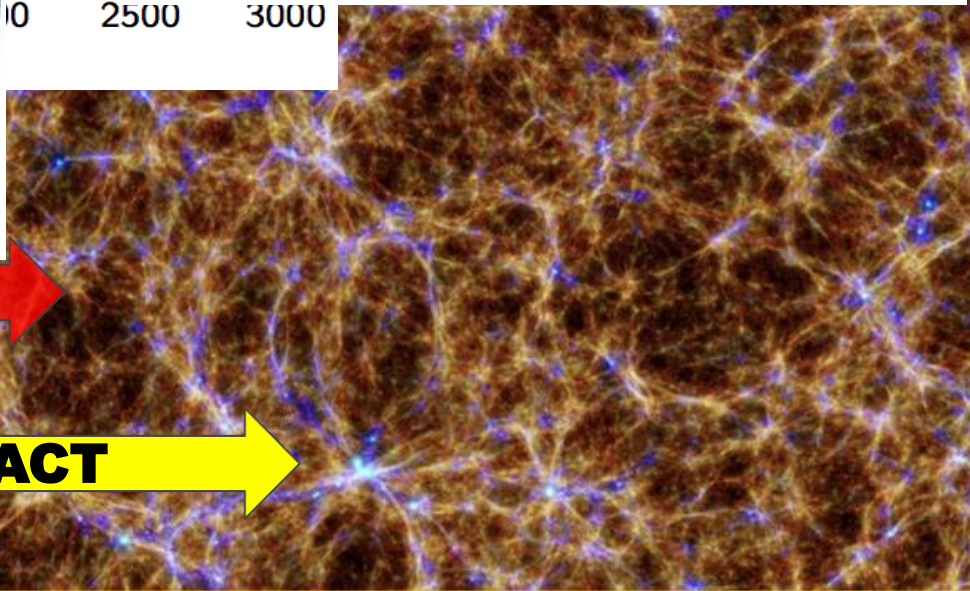
Cluster Cosmology and PLANCK ...



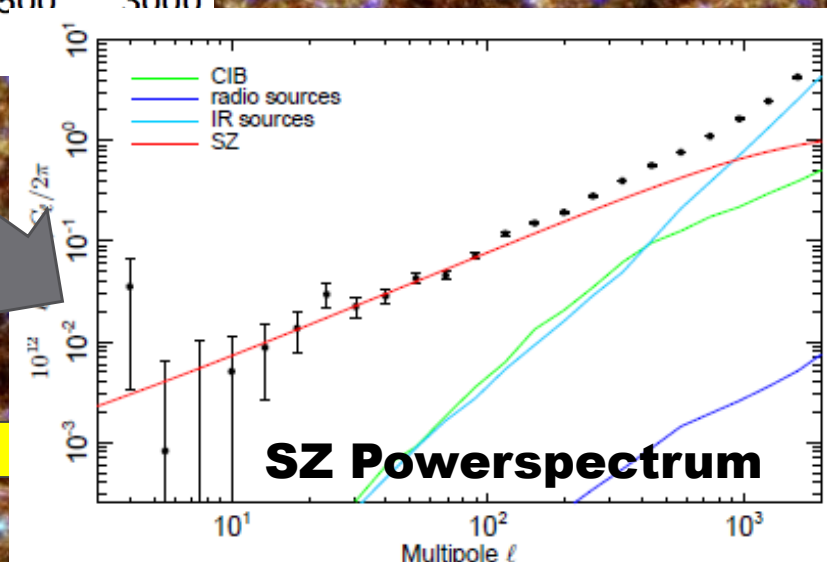
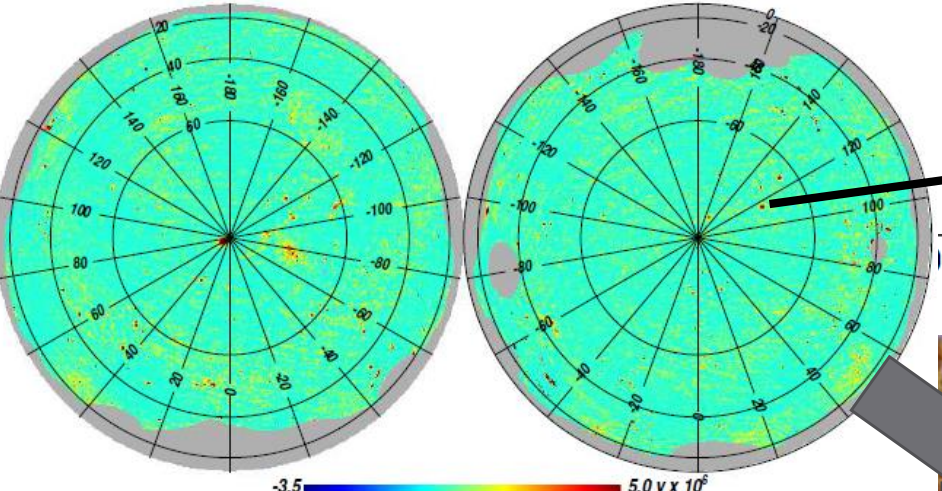
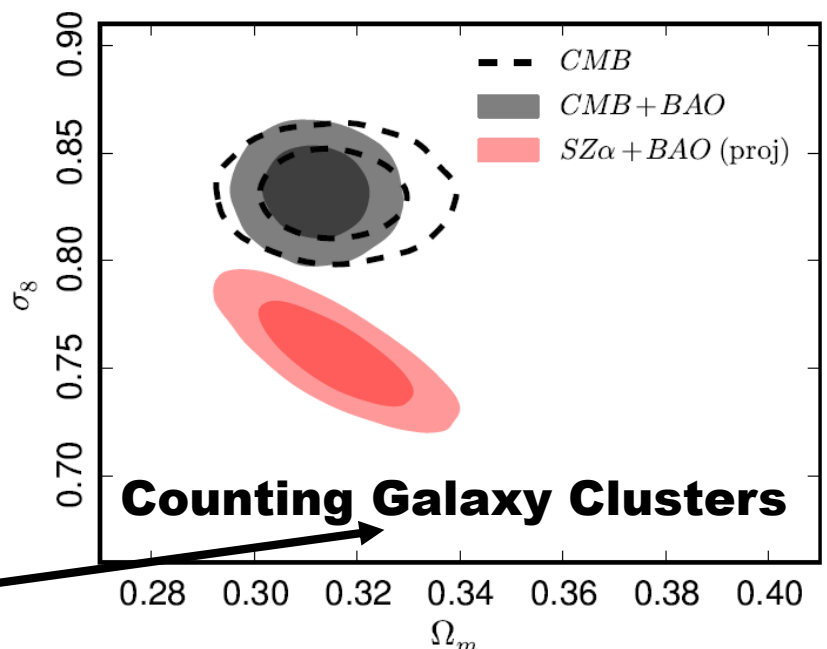
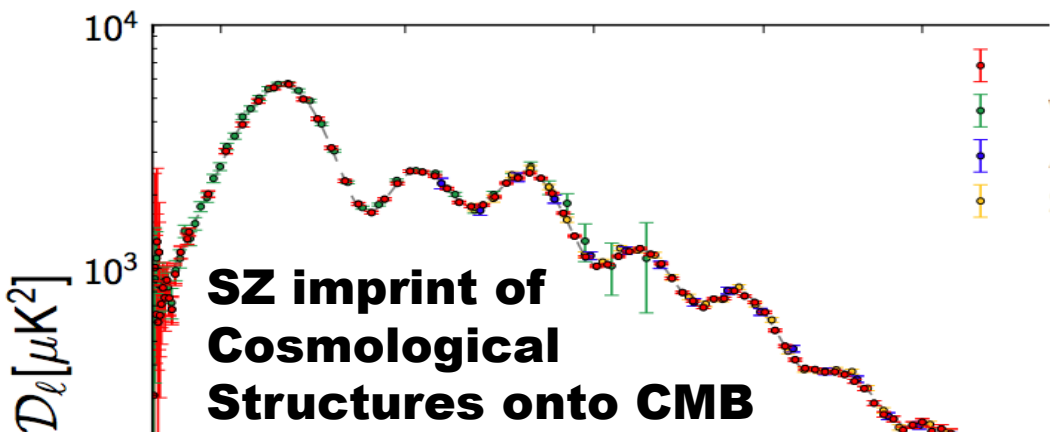
Planck →



SPT und ACT →



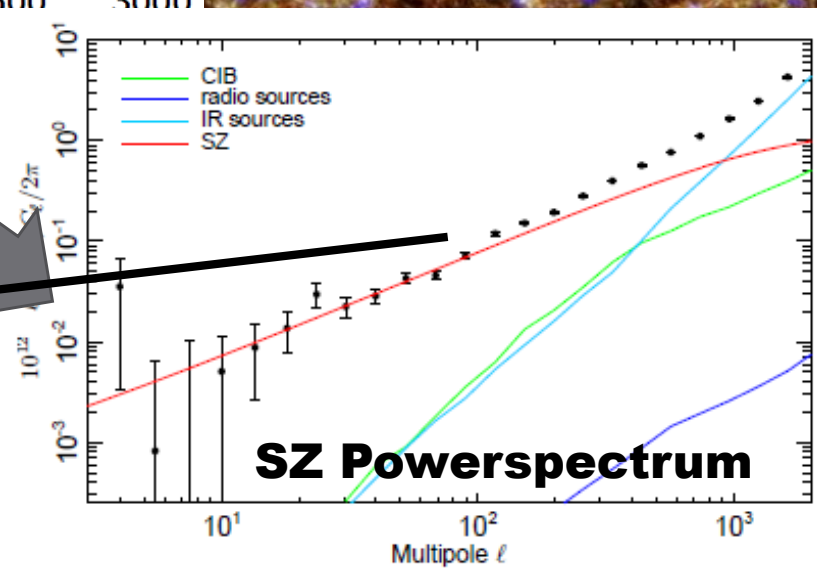
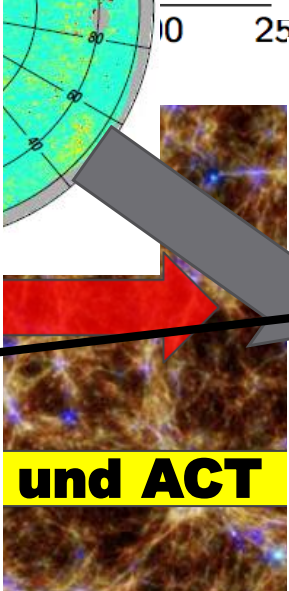
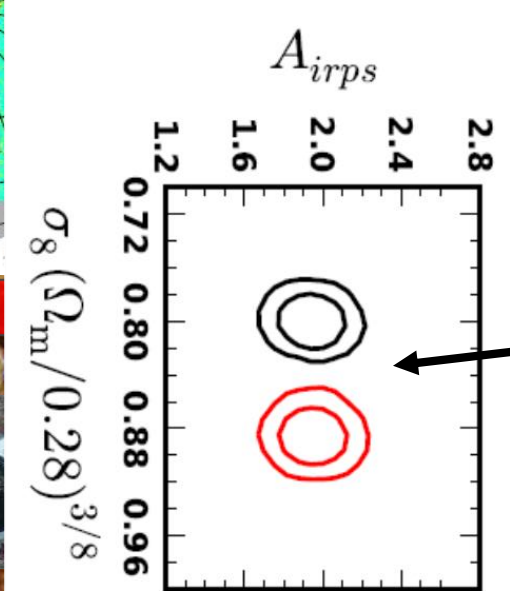
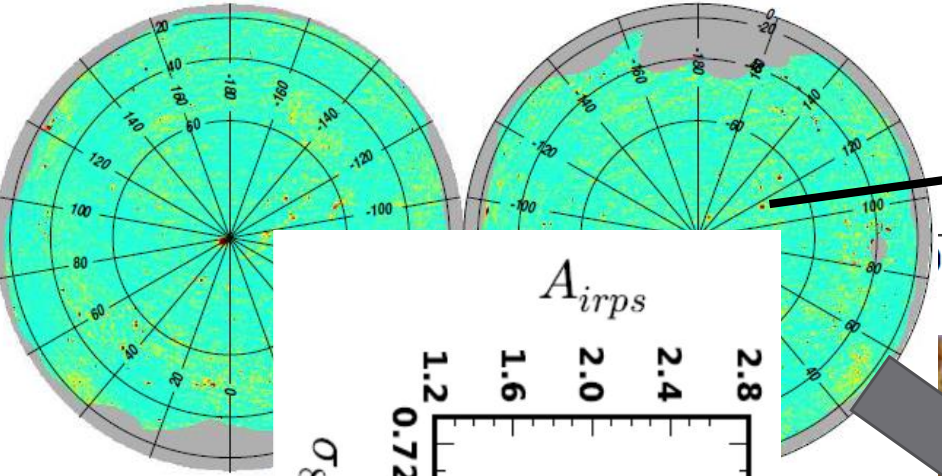
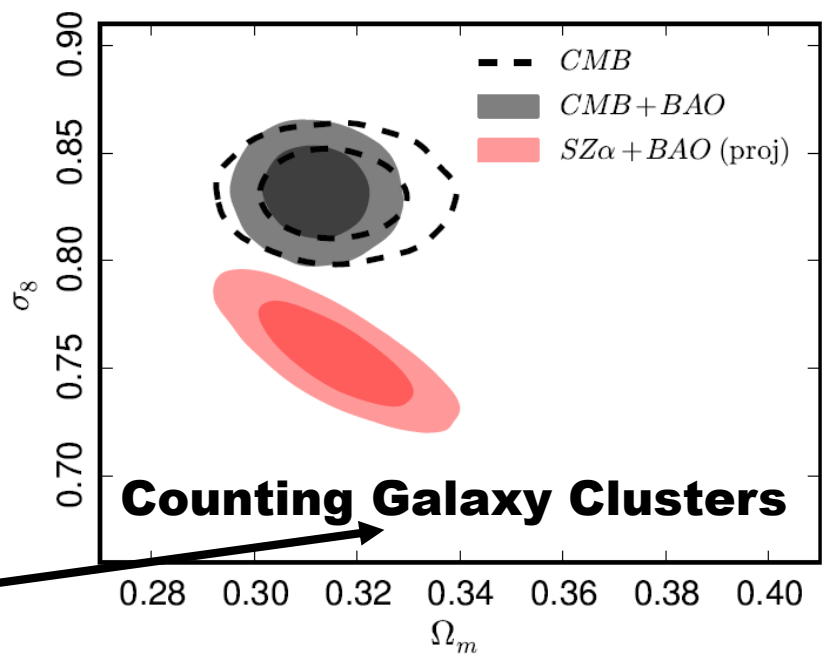
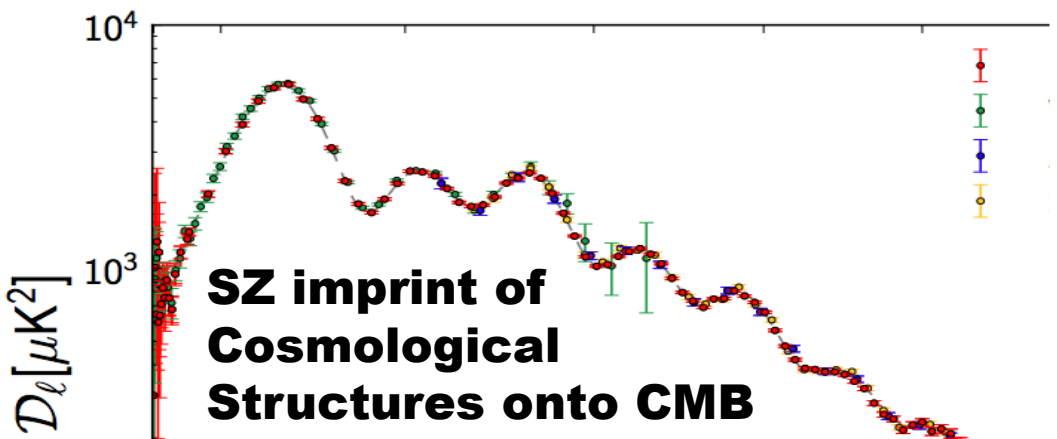
Cluster Cosmology and PLANCK ...



Planck

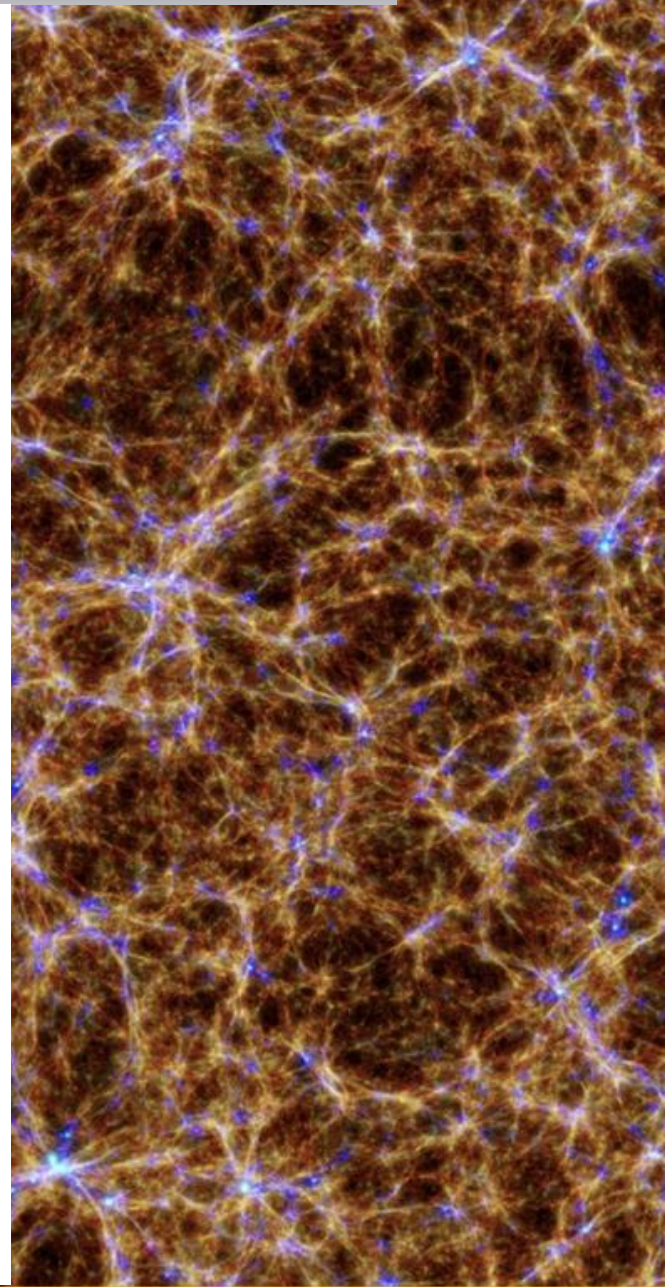
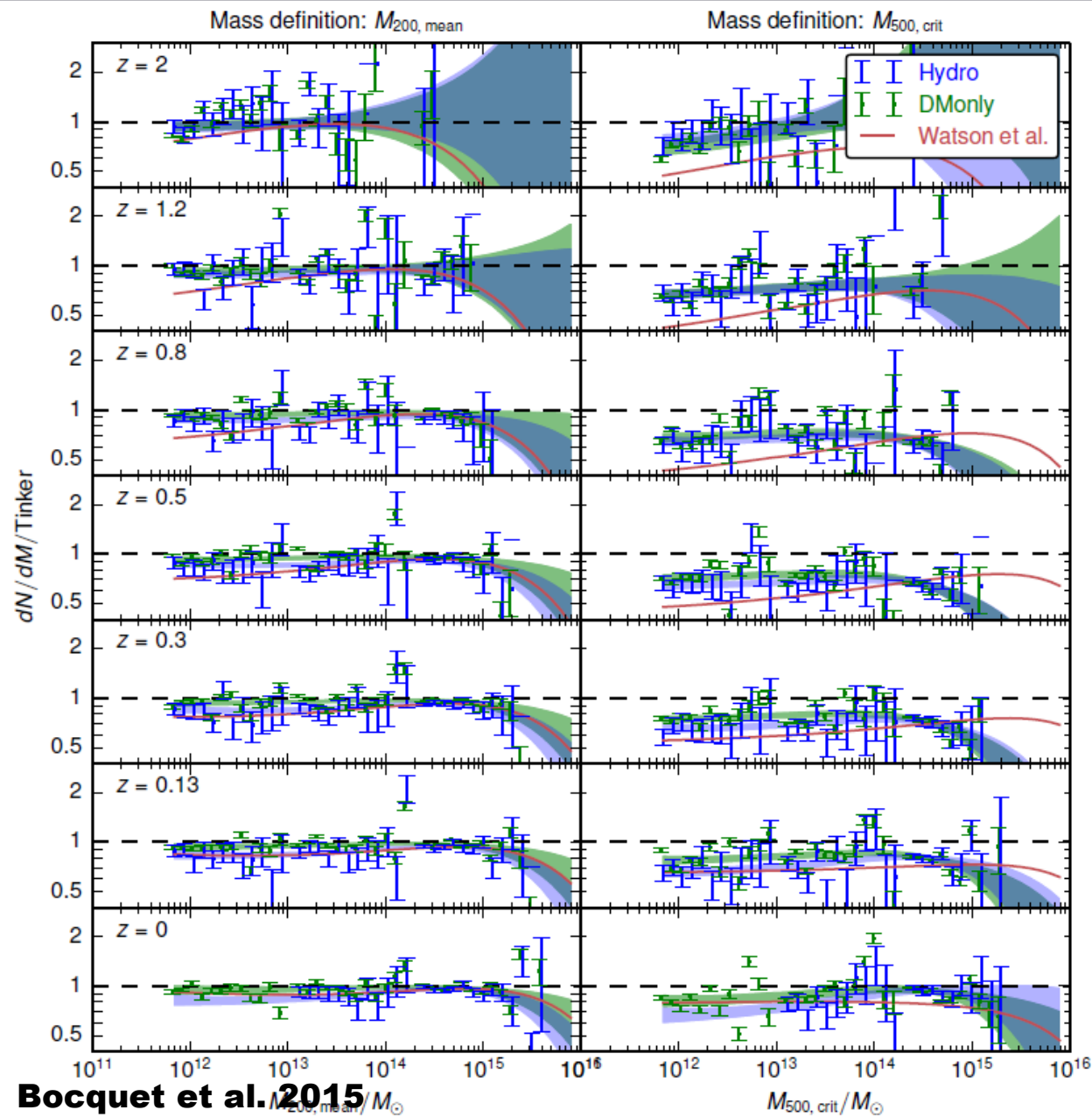


Cluster Cosmology and PLANCK ...

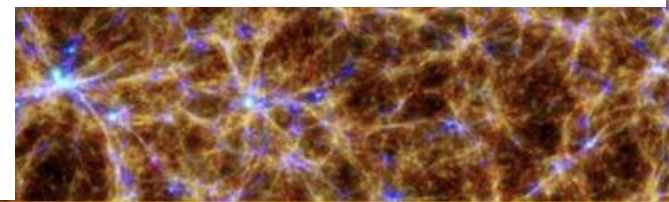
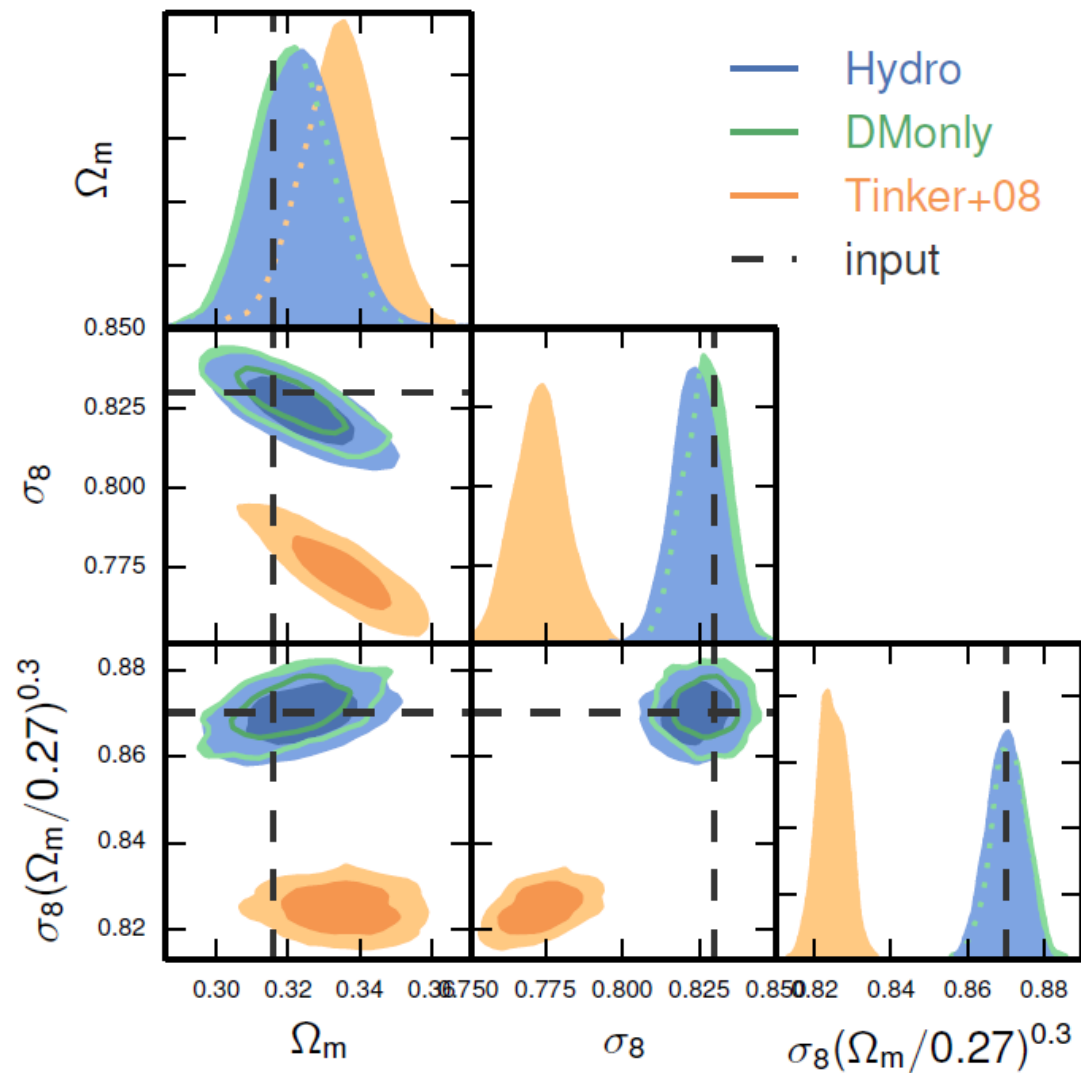
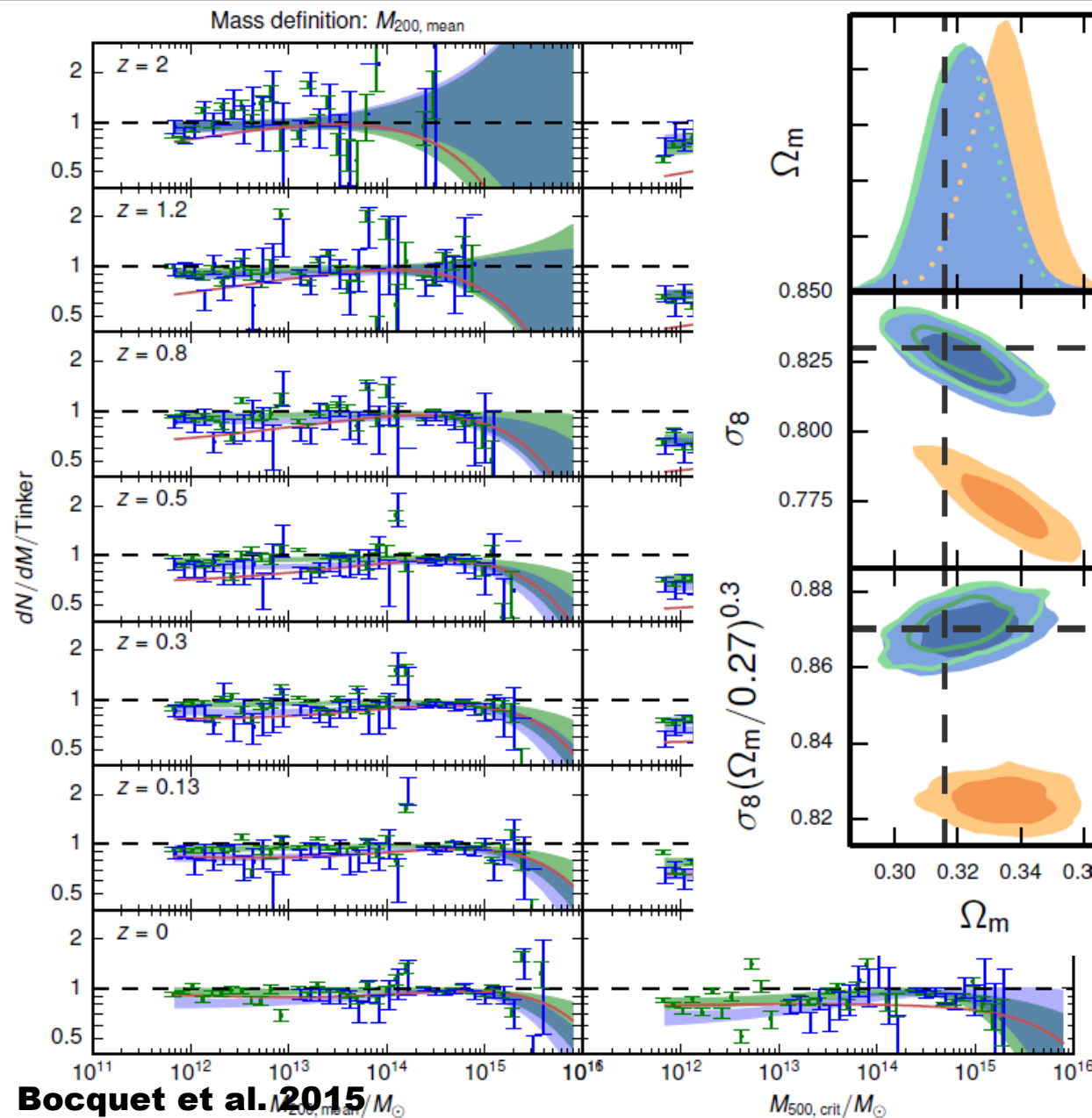
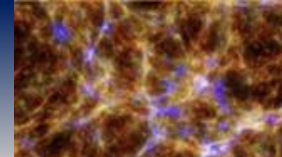


und ACT

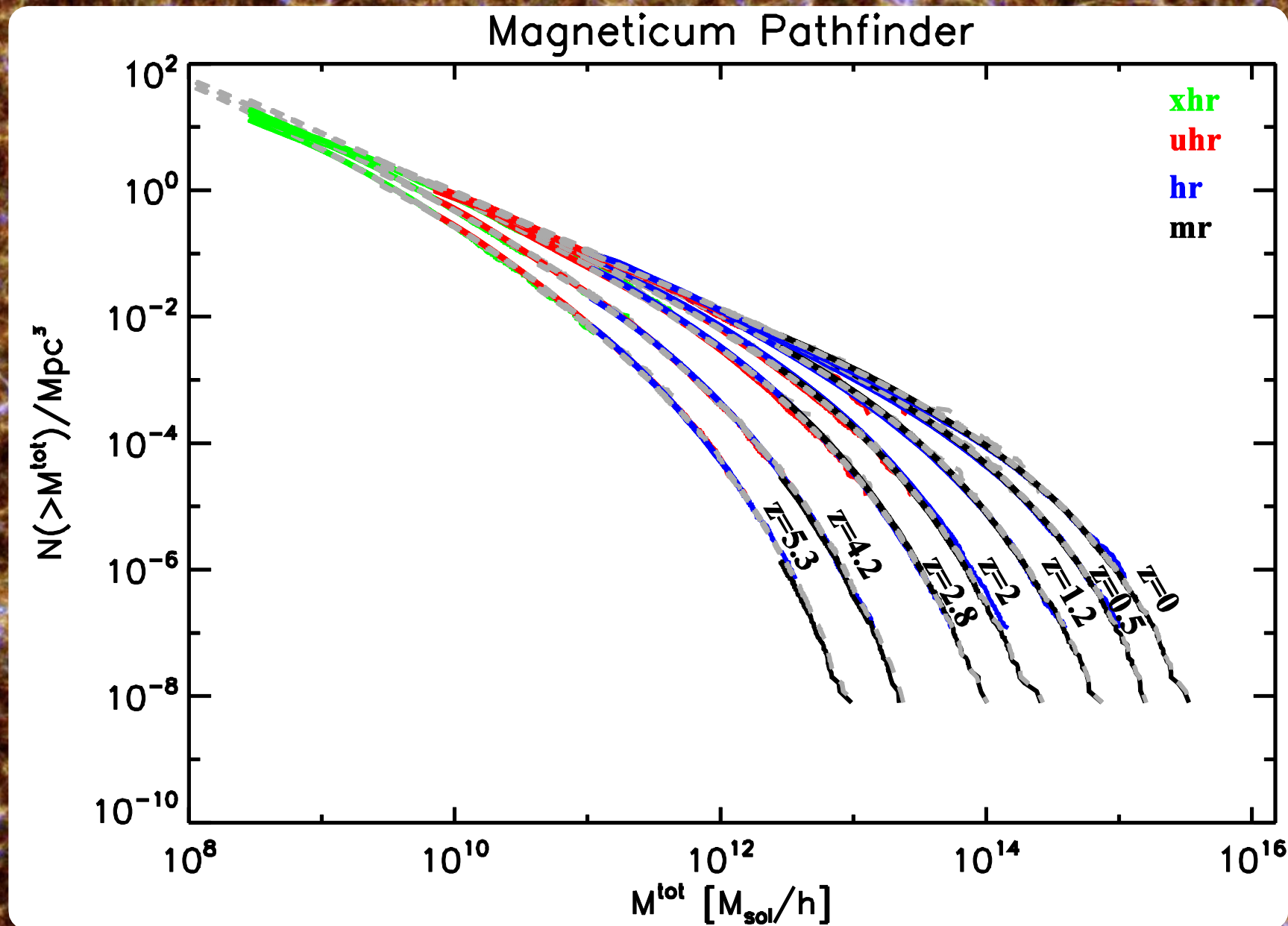
Using Magneticum Pathfinder



Using Magneticum Pathfinder

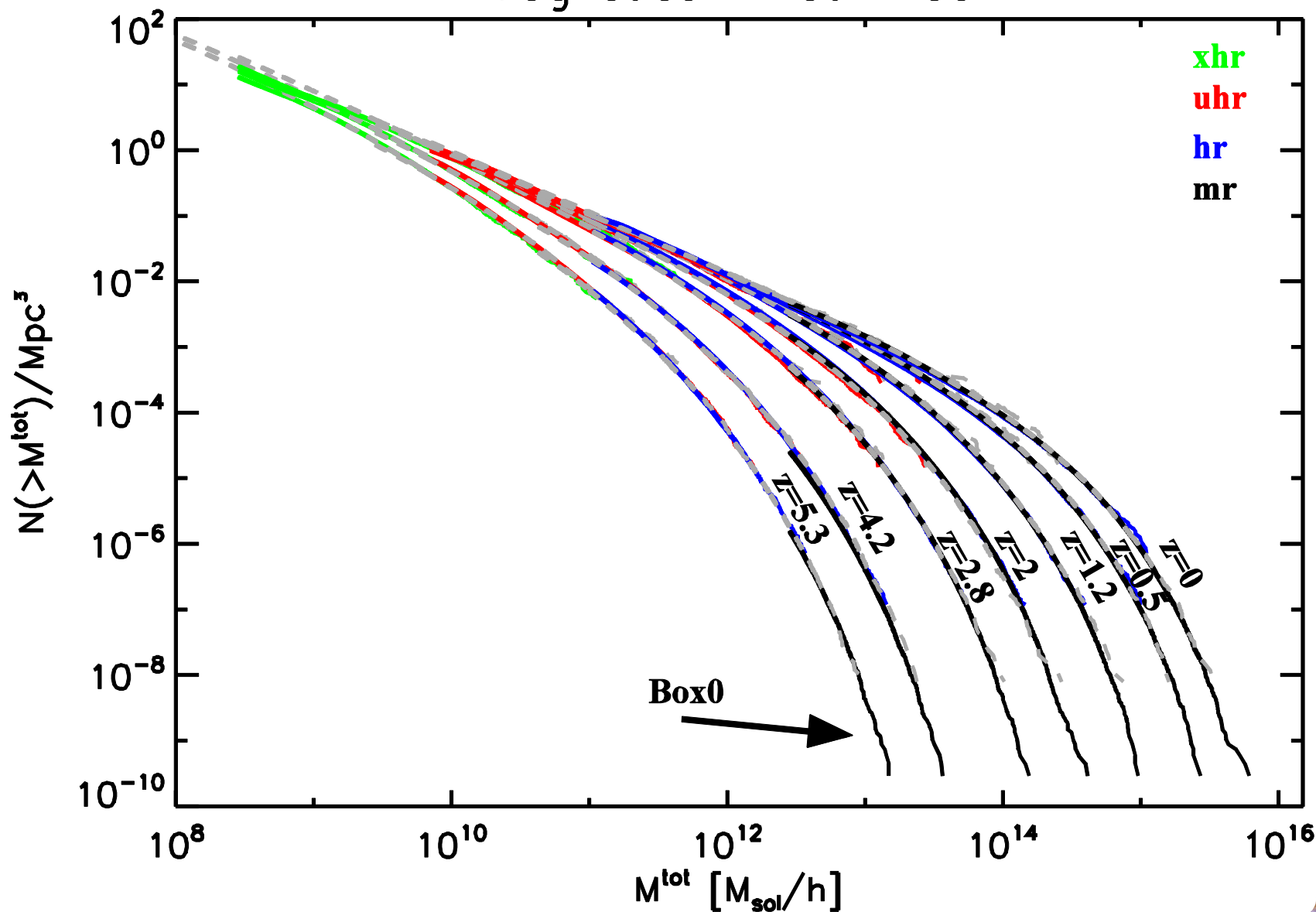


Verifying with Magneticum



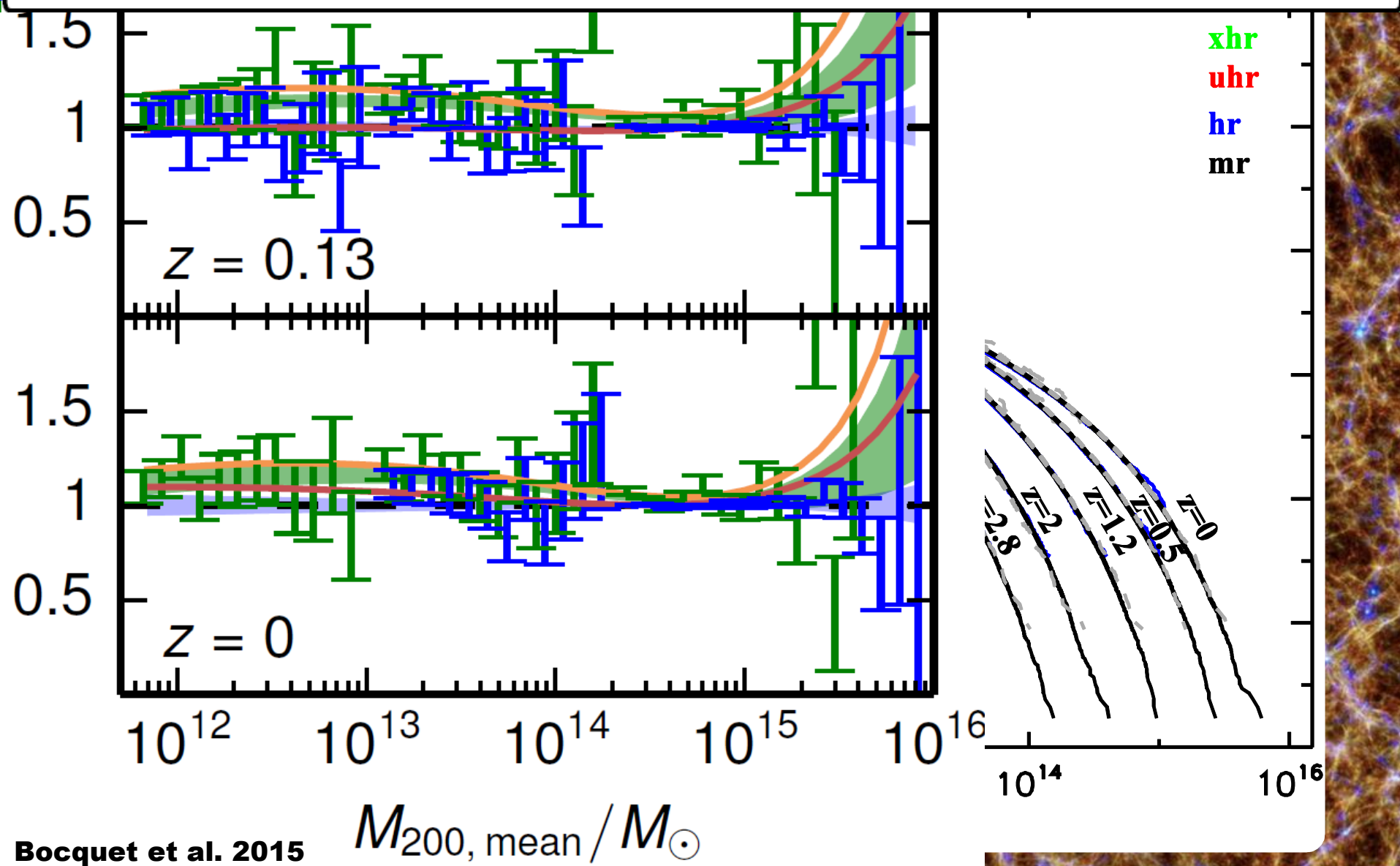
Verifying with Magneticum

Magneticum Pathfinder



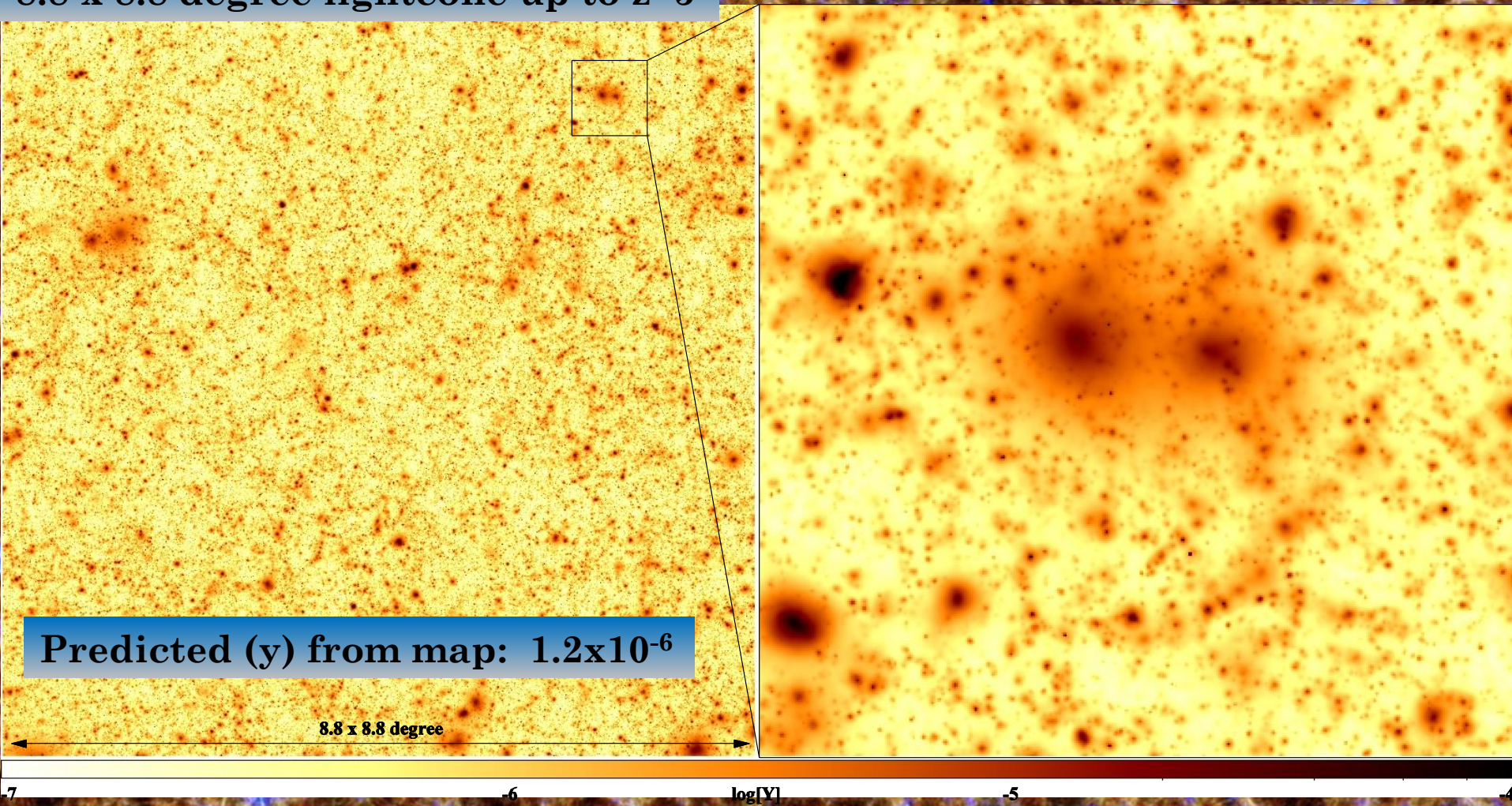
Verifying with Magnesium

Hydro DMonly Watson et al. Tinker et al.



Magneticum Pathfinder SZ Maps

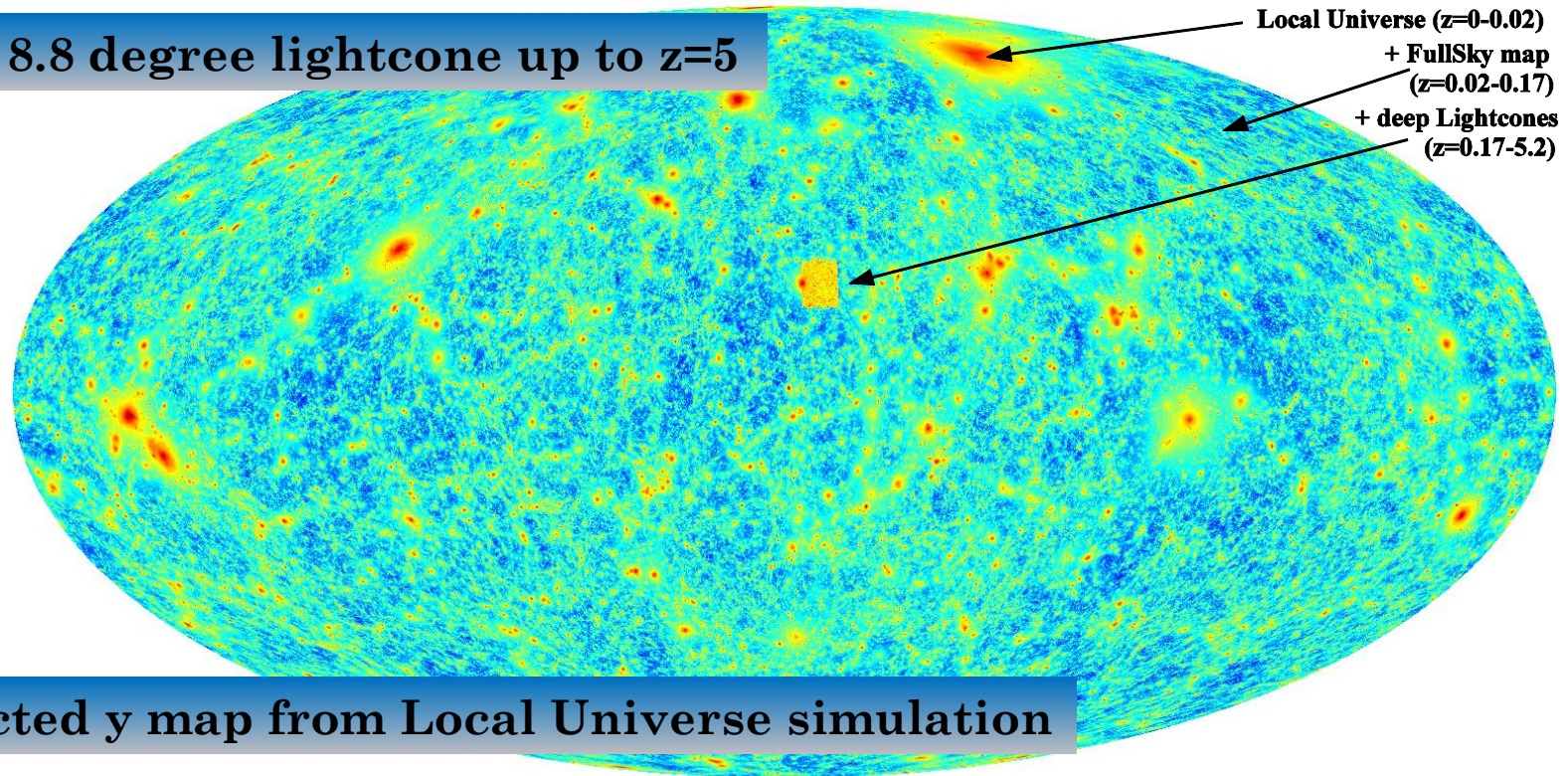
8.8 x 8.8 degree lightcone up to $z=5$



Reconstructed (y) from public PLANCK data:
 $5.4 \times 10^{-8} < (y) < 2.2 \times 10^{-6}$ (Khatri & Sumyaev 2015)

Magneticum Pathfinder SZ Maps

8.8 x 8.8 degree lightcone up to $z=5$

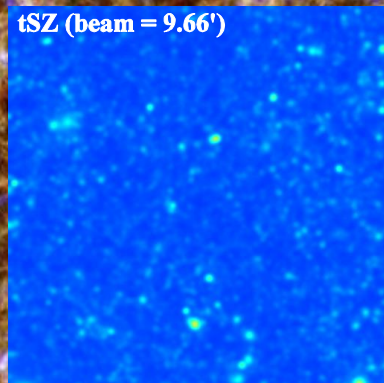


Local Universe ($z=0-0.02$)
+ FullSky map
($z=0.02-0.17$)
+ deep Lightcones
($z=0.17-5.2$)

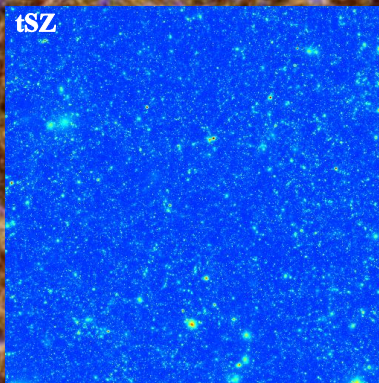
Predicted y map from Local Universe simulation



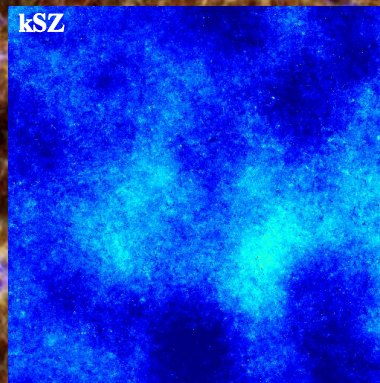
tSZ (beam = 9.66')



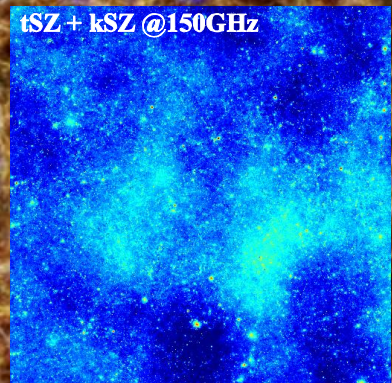
tSZ



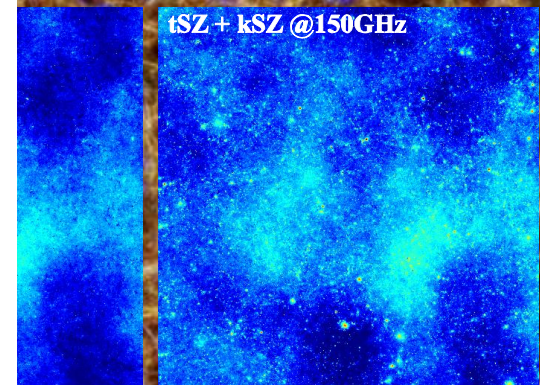
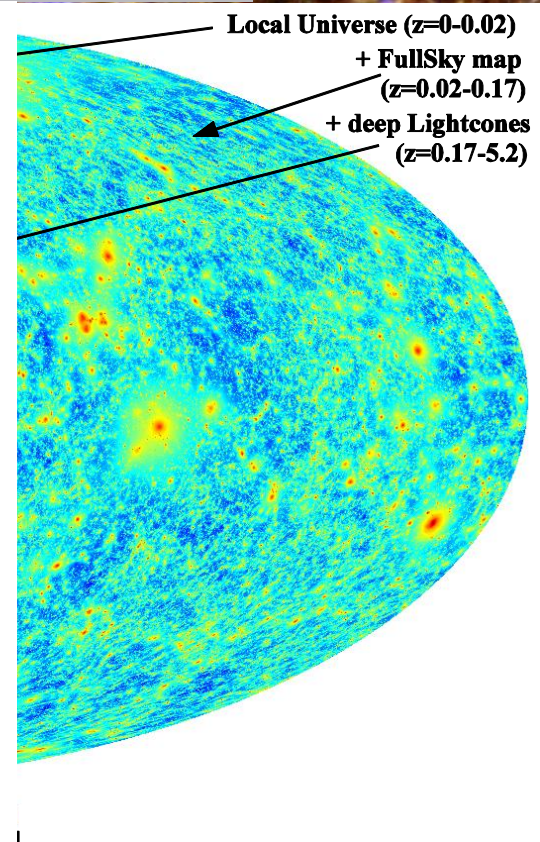
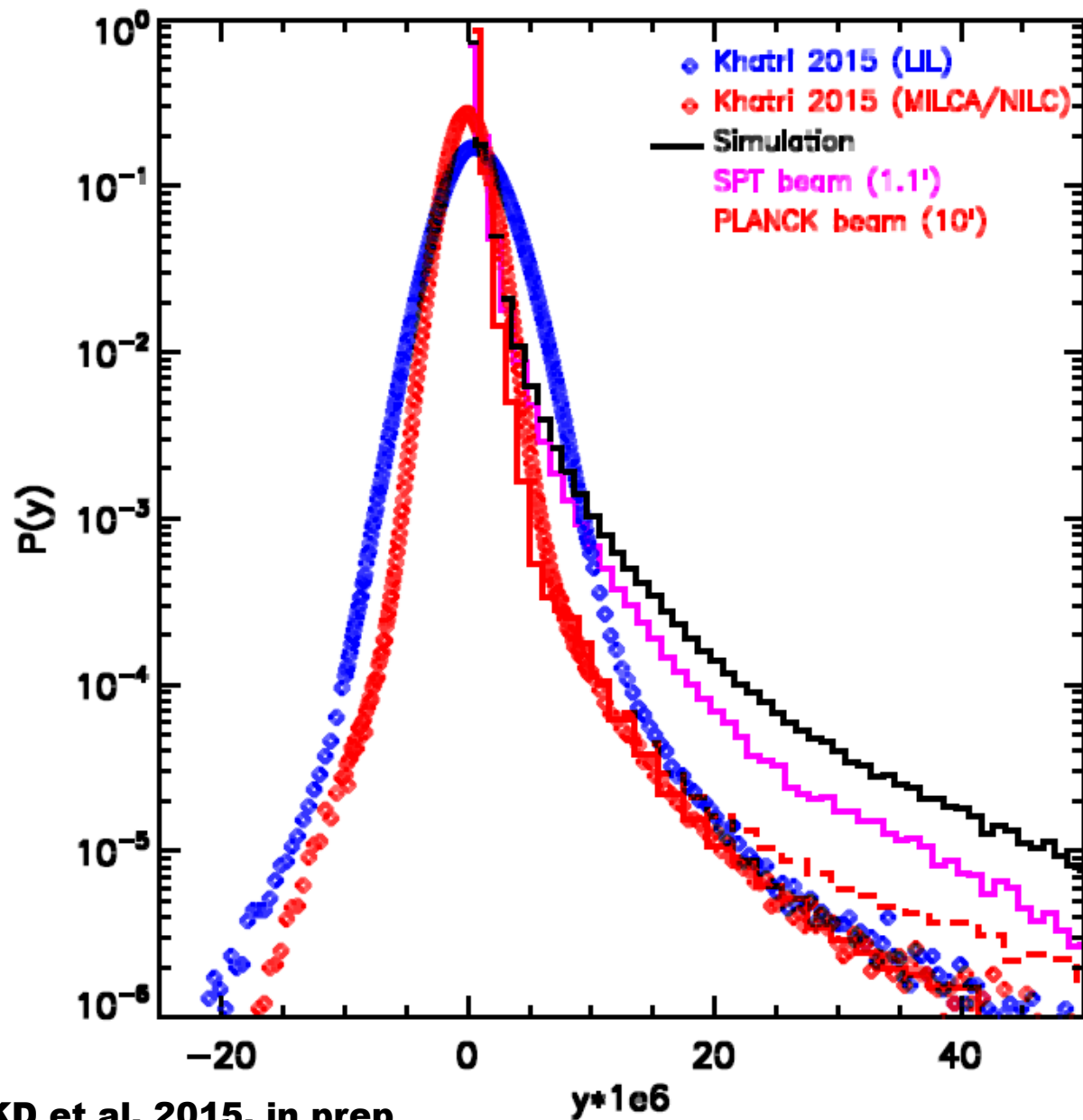
kSZ



tSZ + kSZ @150GHz

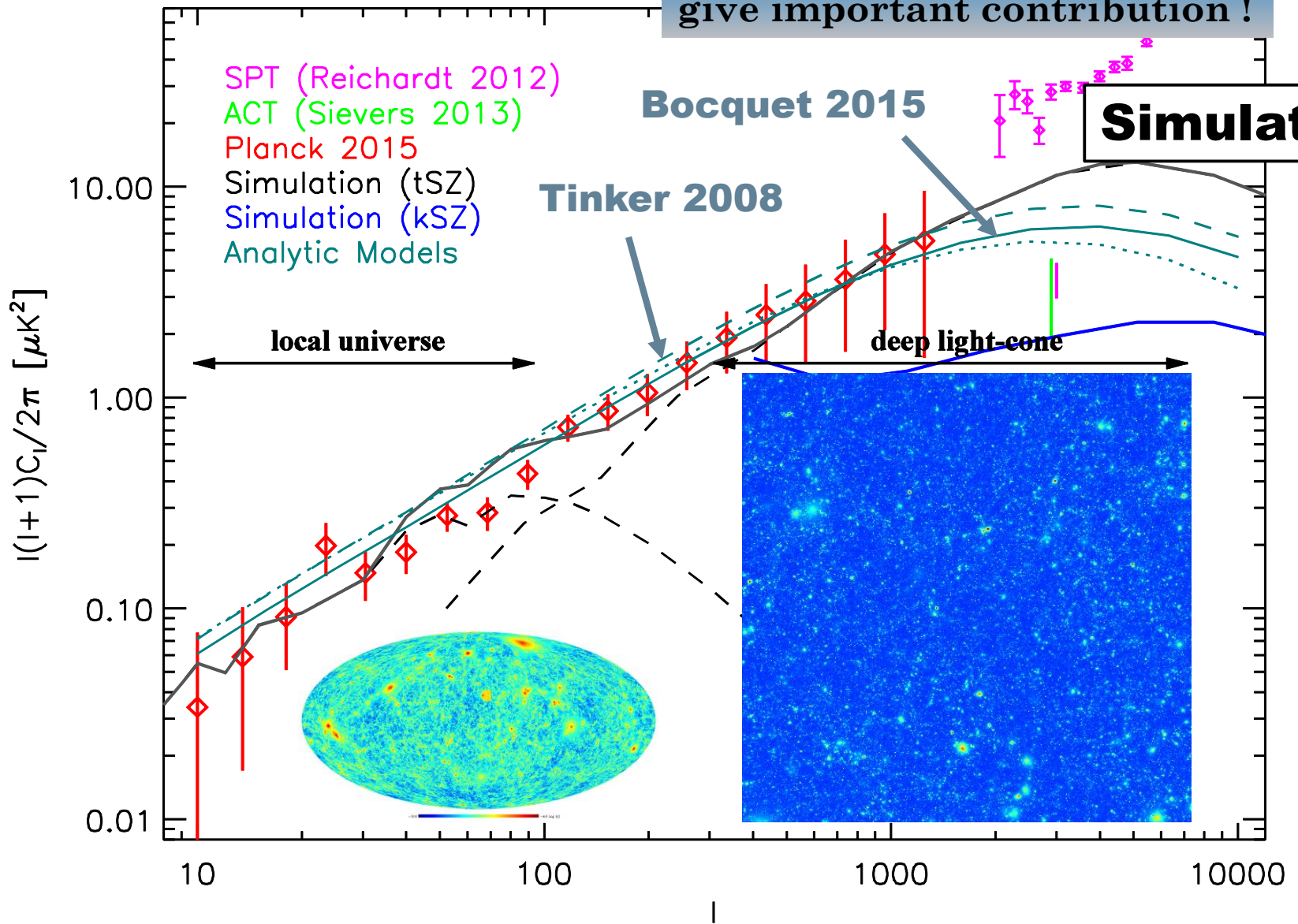


SZ y -distribution function

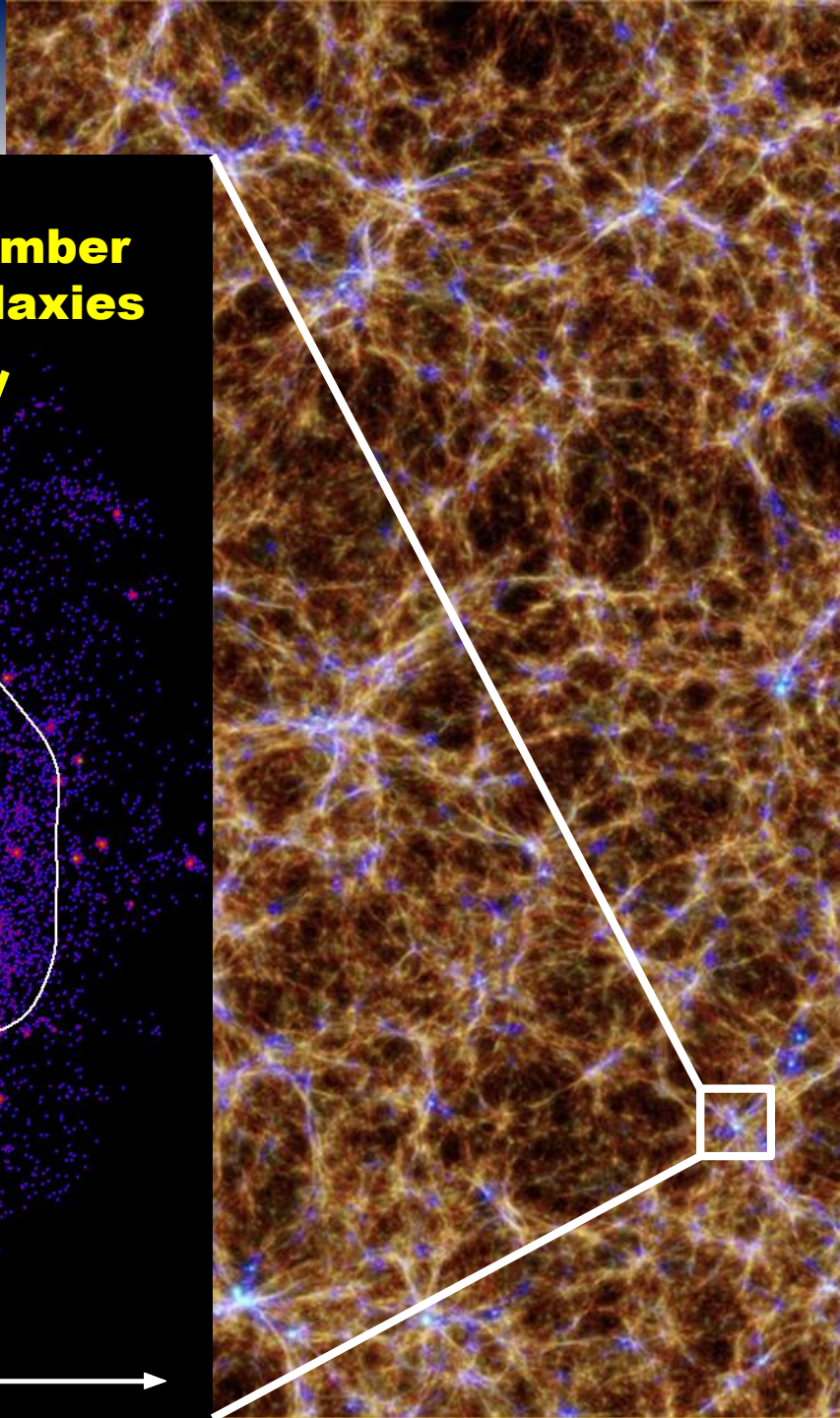
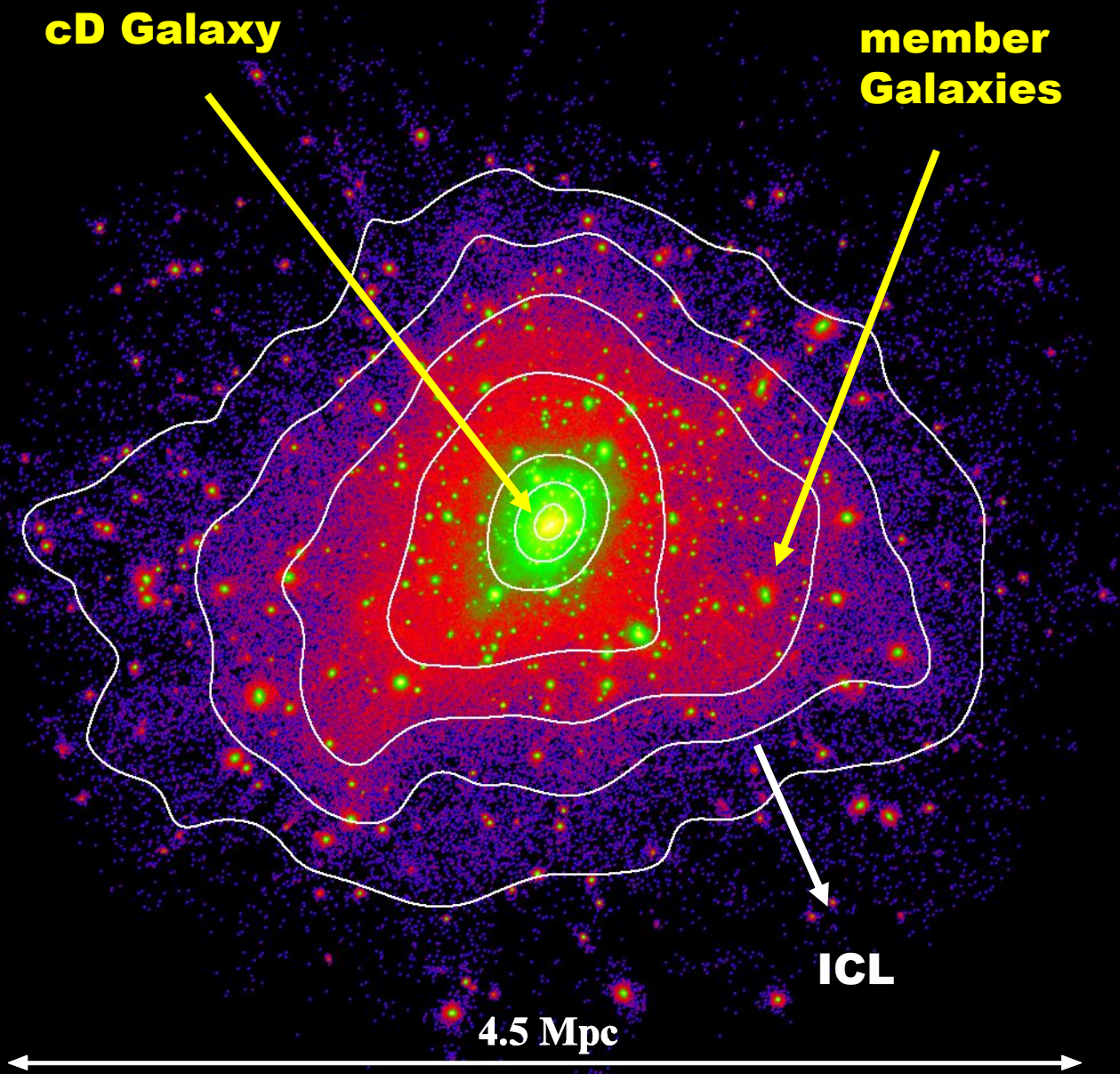


SZ power spektrum

Local Universe simulations
give important contribution !



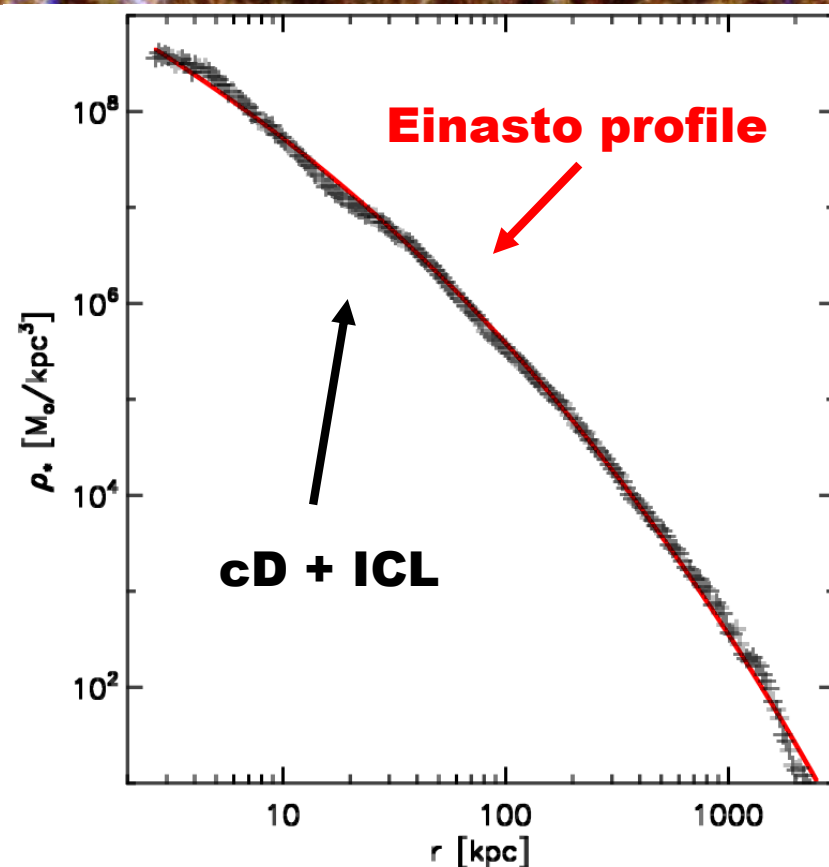
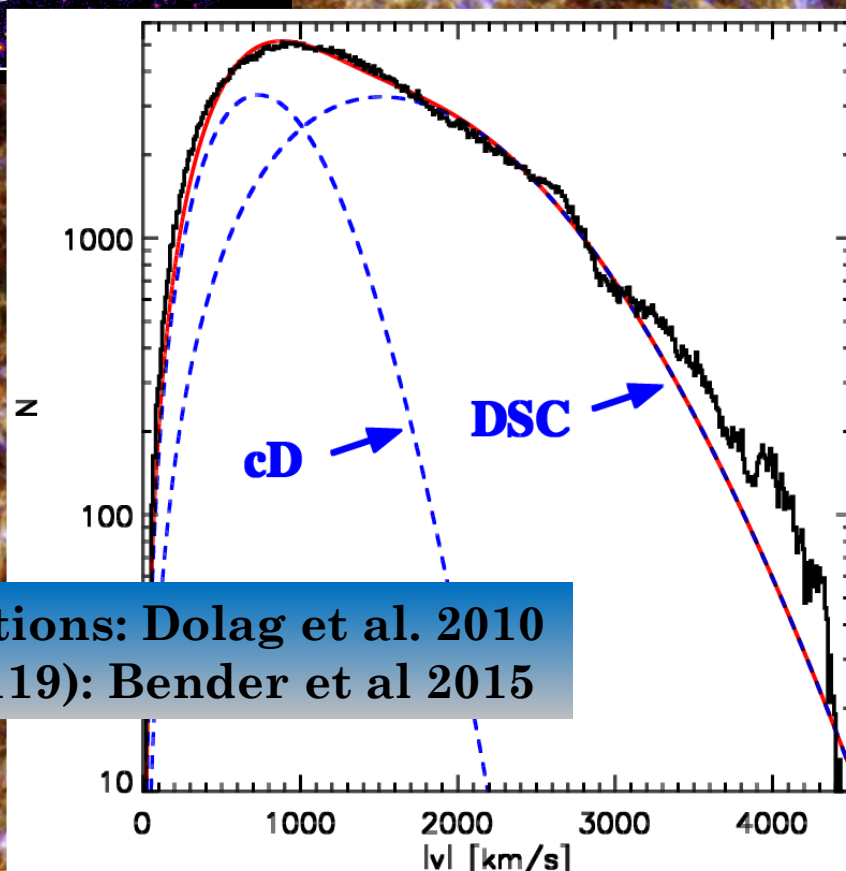
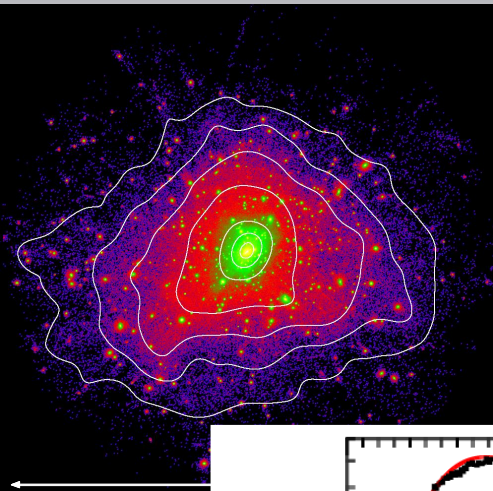
Intra cluster light



Intra cluster light

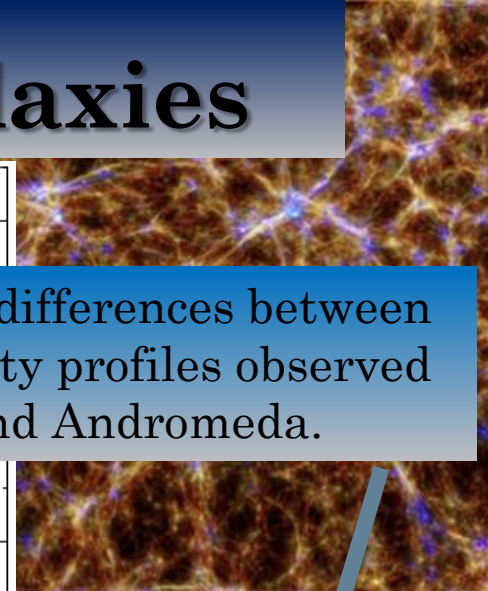
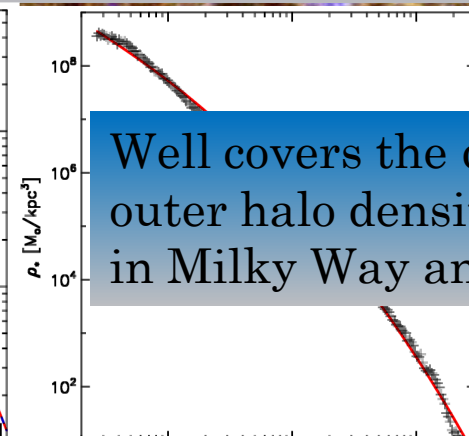
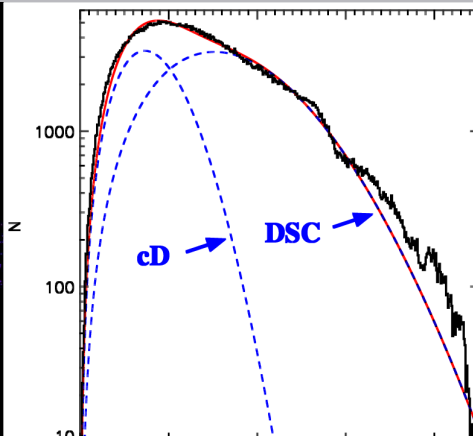
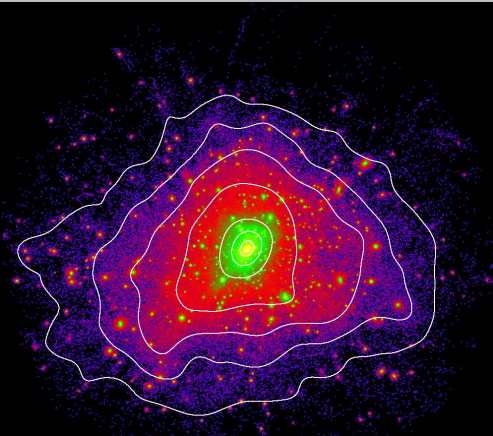
Einasto profile

$$\rho_{-2} \exp \left\{ -\frac{2}{\alpha_{Ein}} \left[\left(\frac{r}{r_{-2}} \right)^{\alpha_{Ein}} - 1 \right] \right\}$$

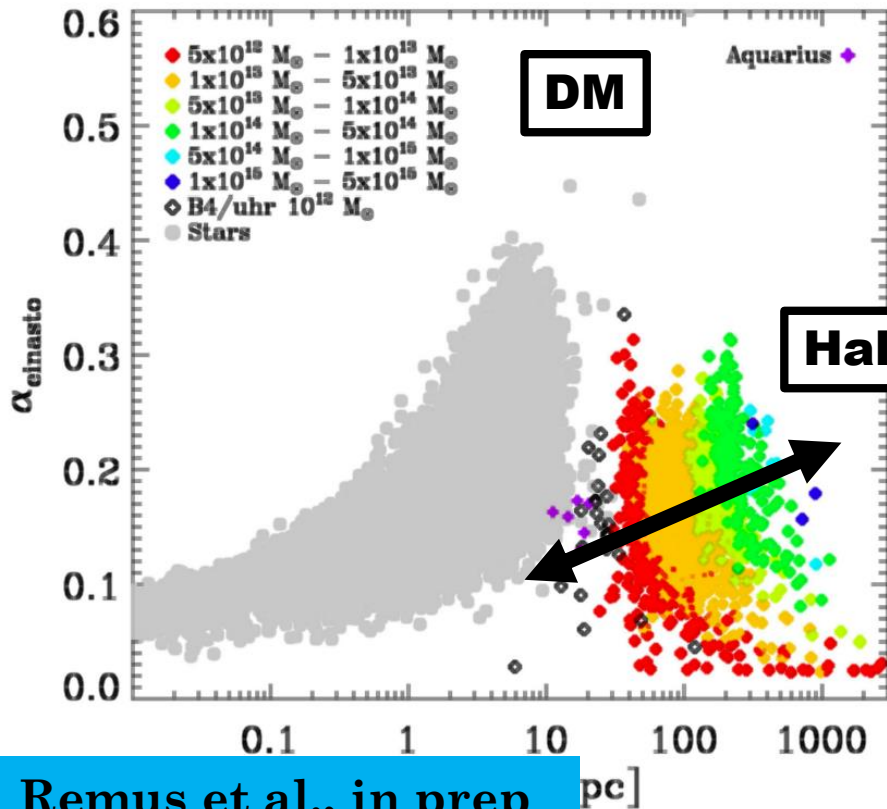


Simulations: Dolag et al. 2010
Obs (A119): Bender et al 2015

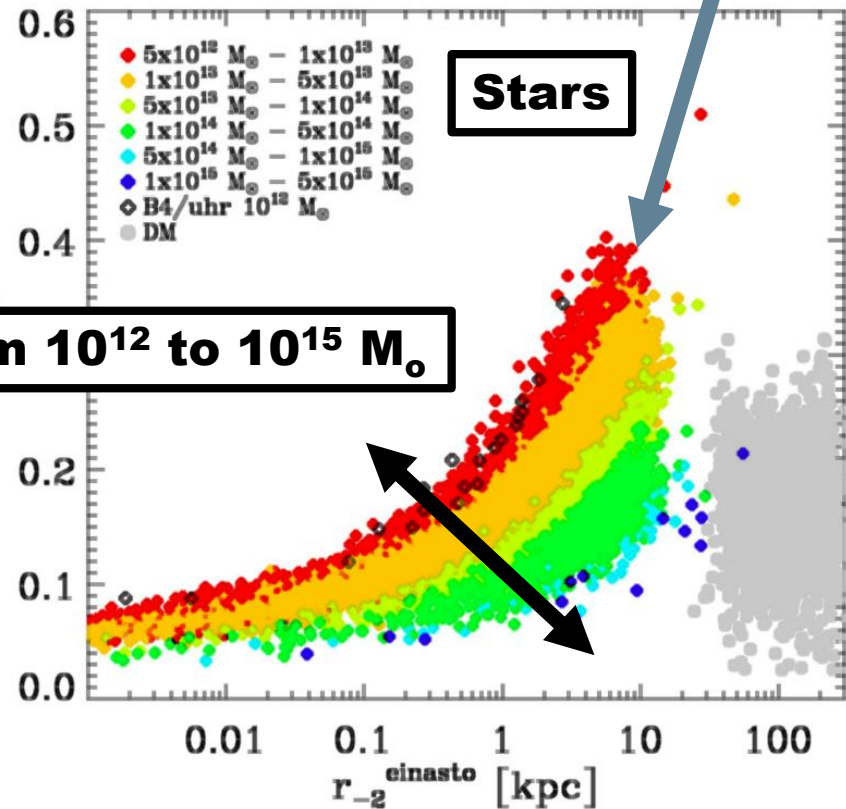
From ICL to outer halos of galaxies



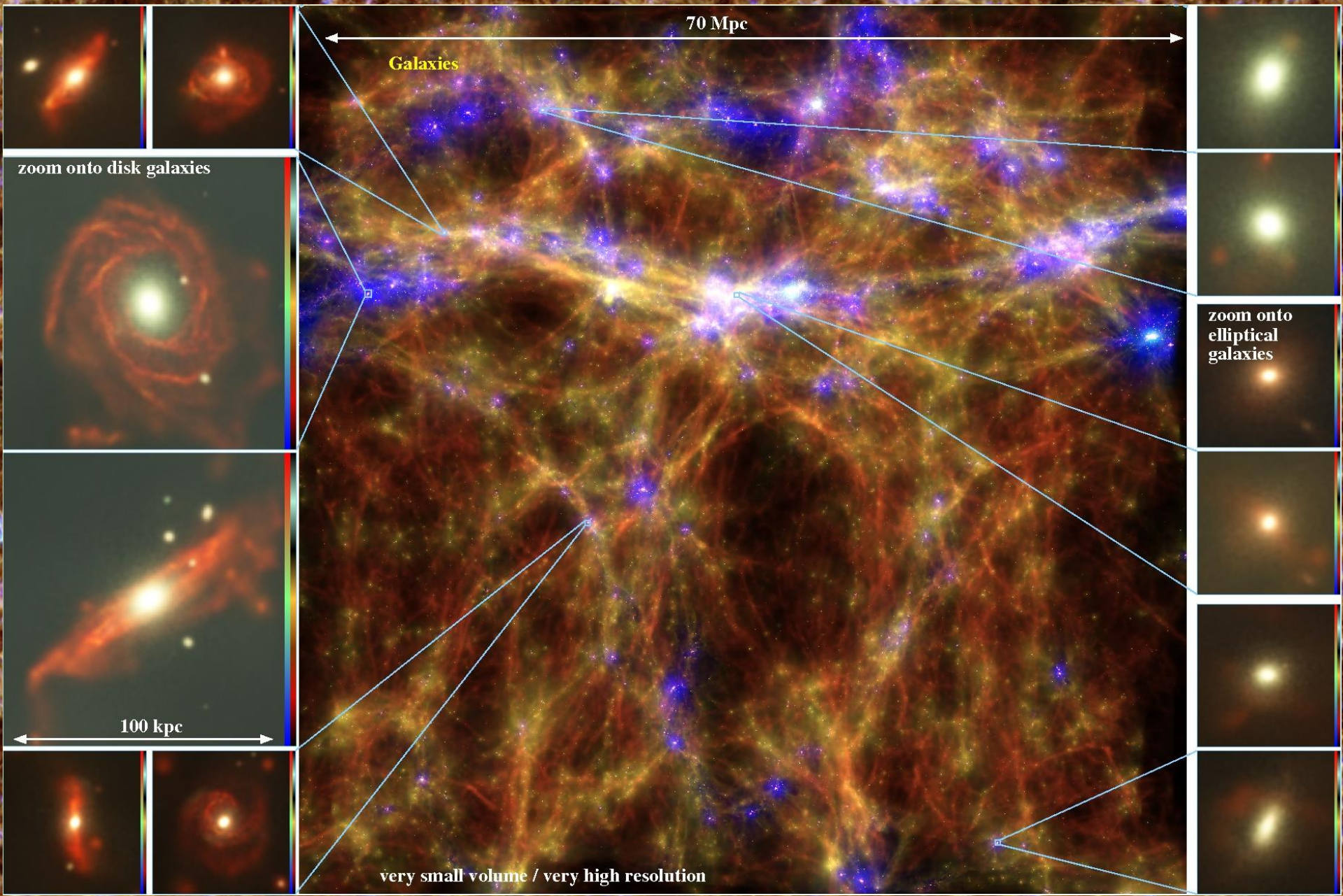
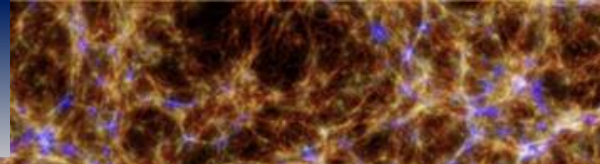
Well covers the differences between outer halo density profiles observed in Milky Way and Andromeda.



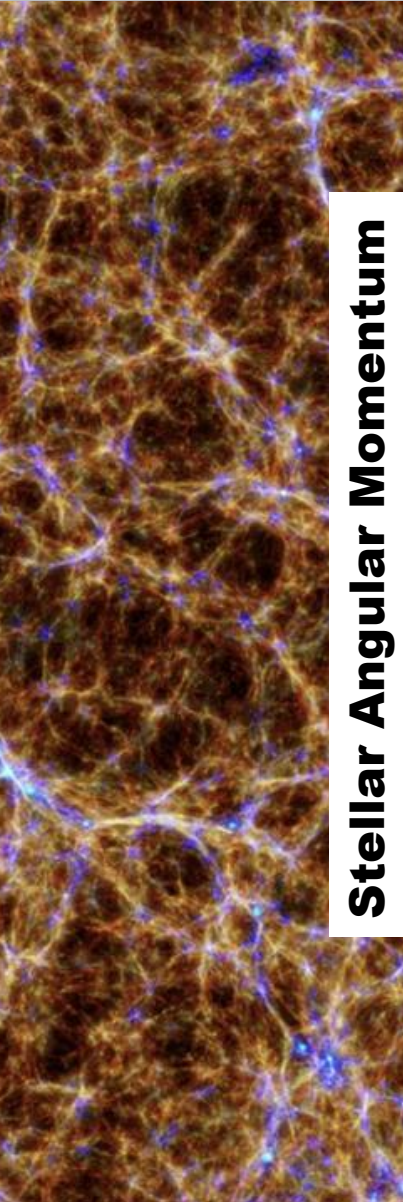
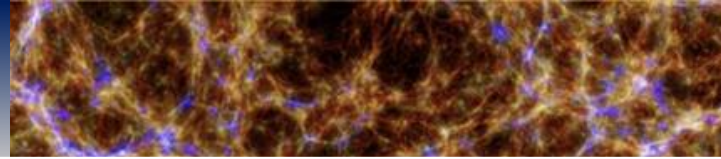
Halos from 10^{12} to $10^{15} M_{\odot}$



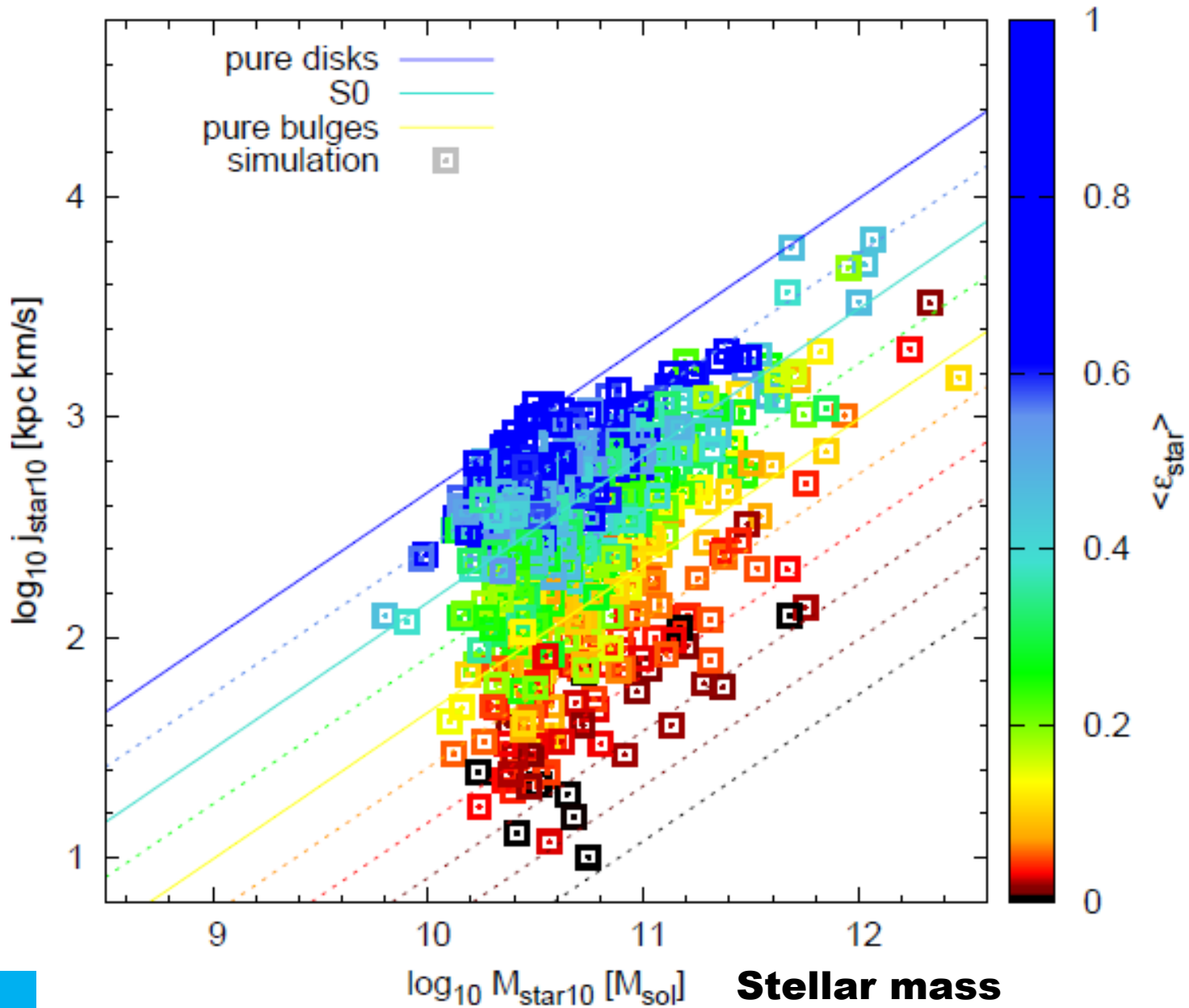
Morphology of galaxies



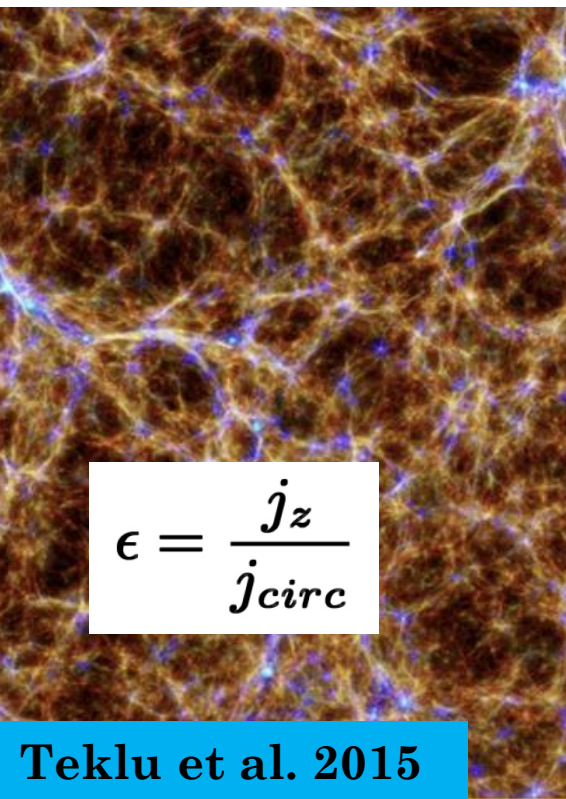
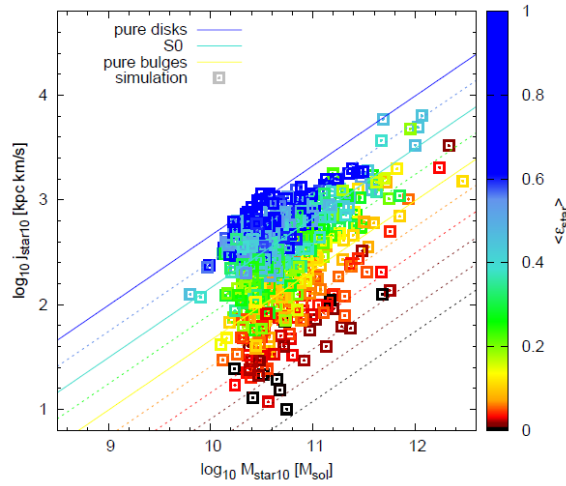
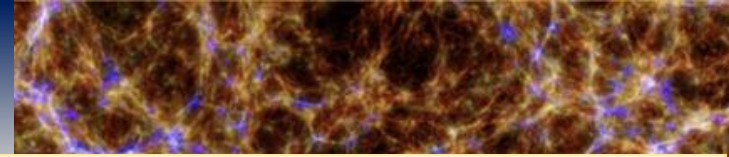
Dynamics of galaxies



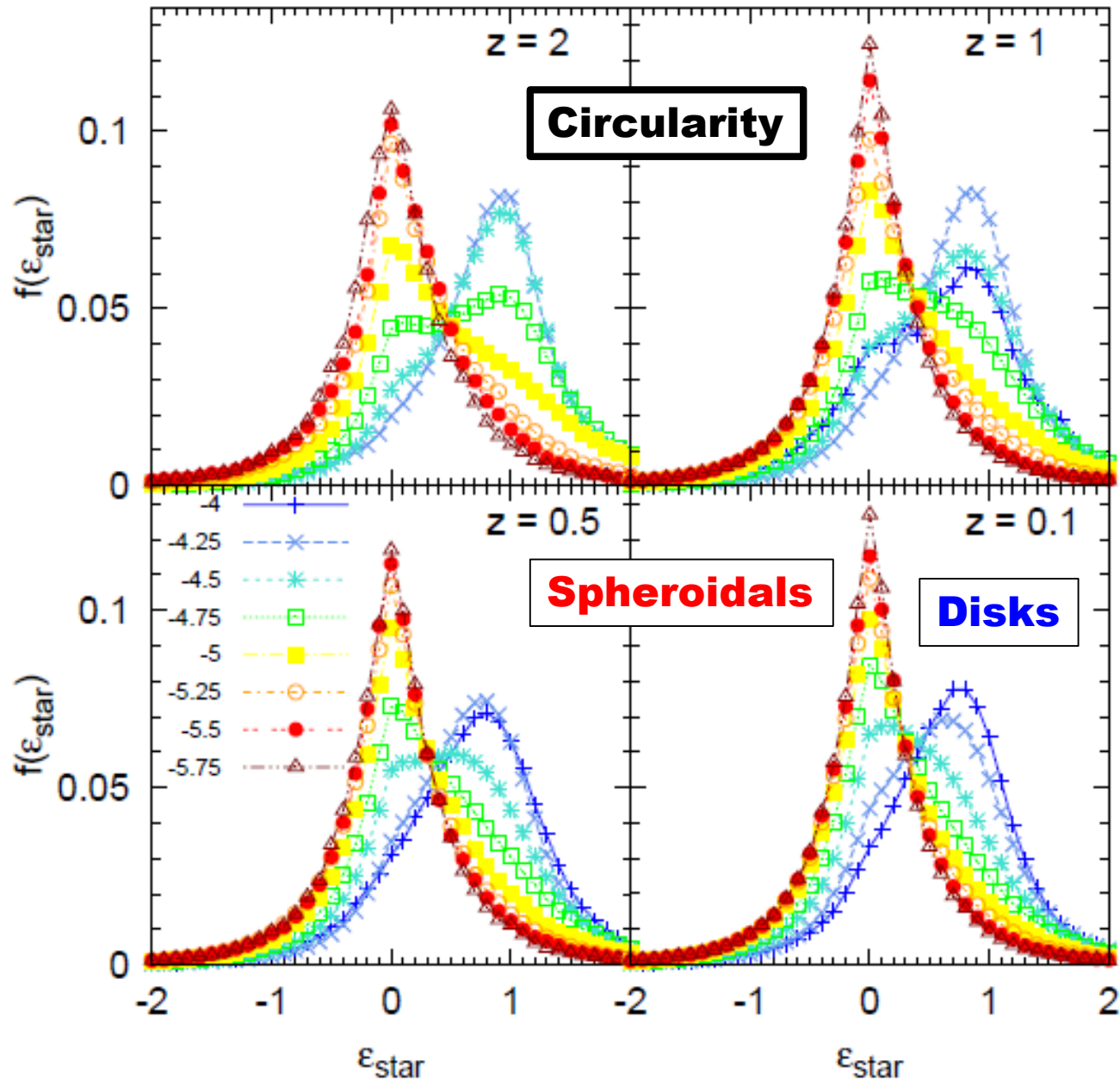
Stellar Angular Momentum



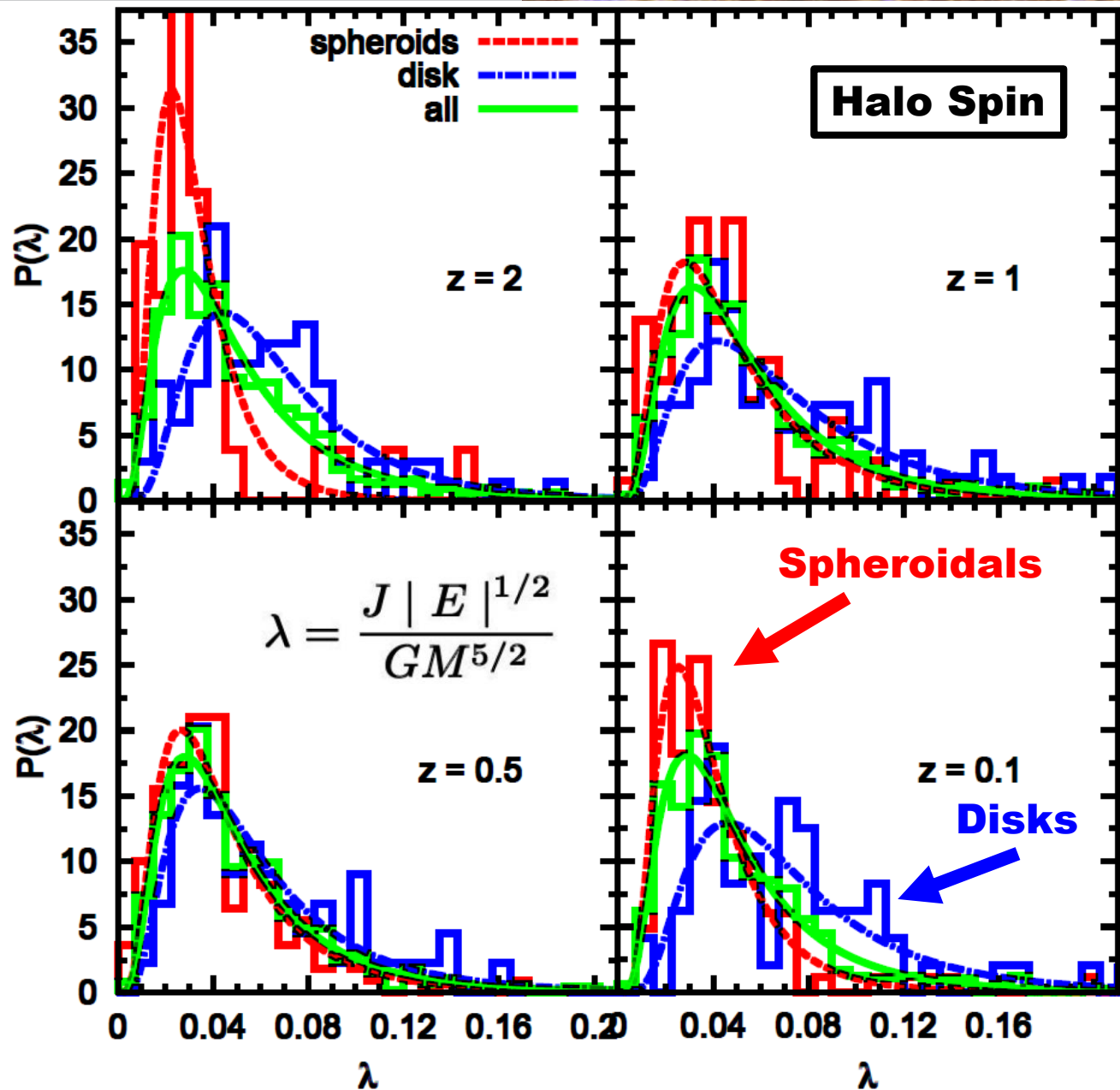
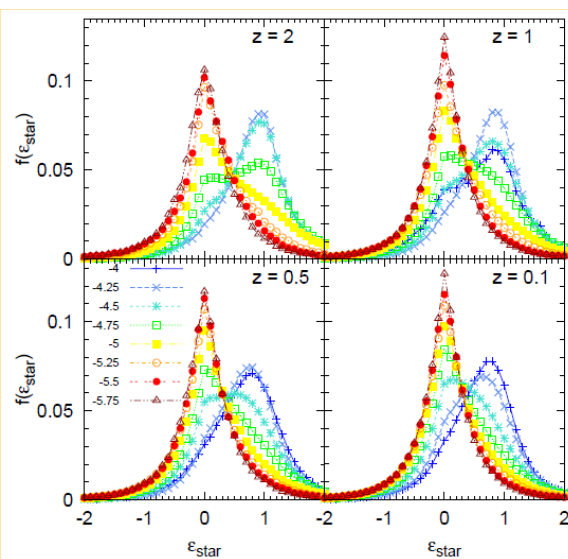
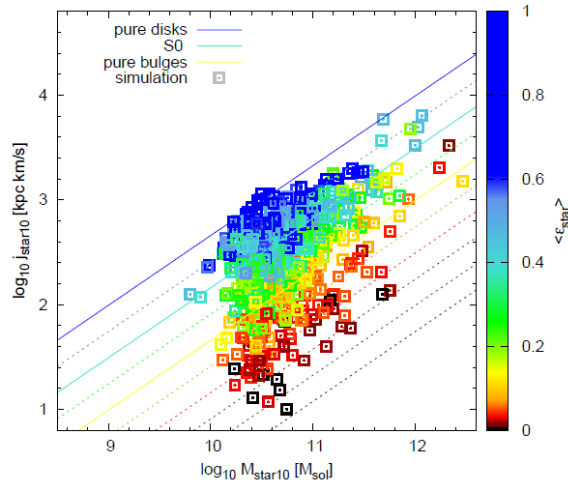
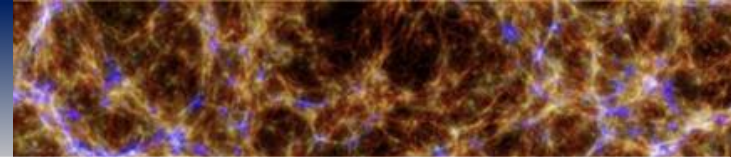
Dynamics of galaxies



$$\epsilon = \frac{j_z}{j_{circ}}$$

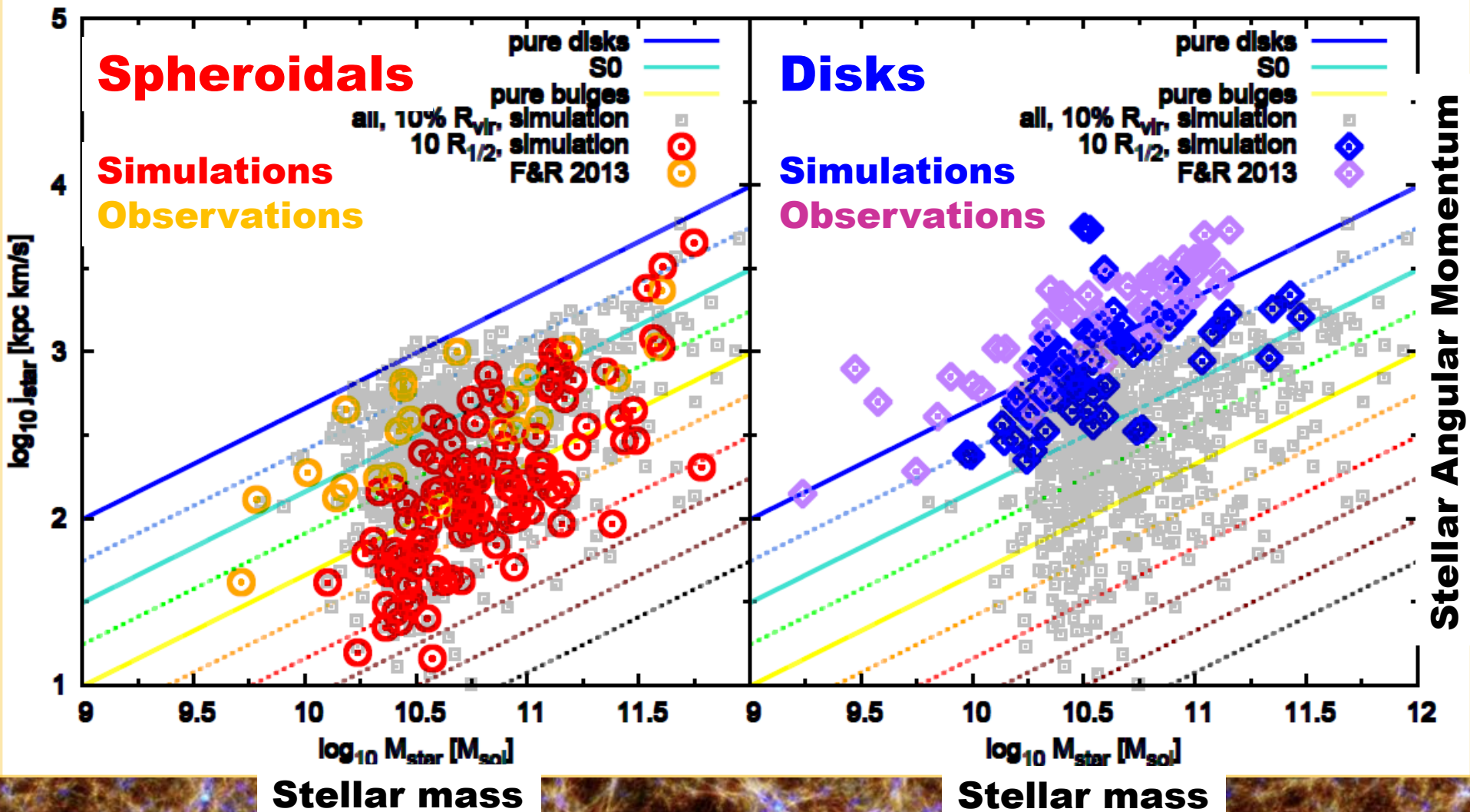


Dynamics of galaxies

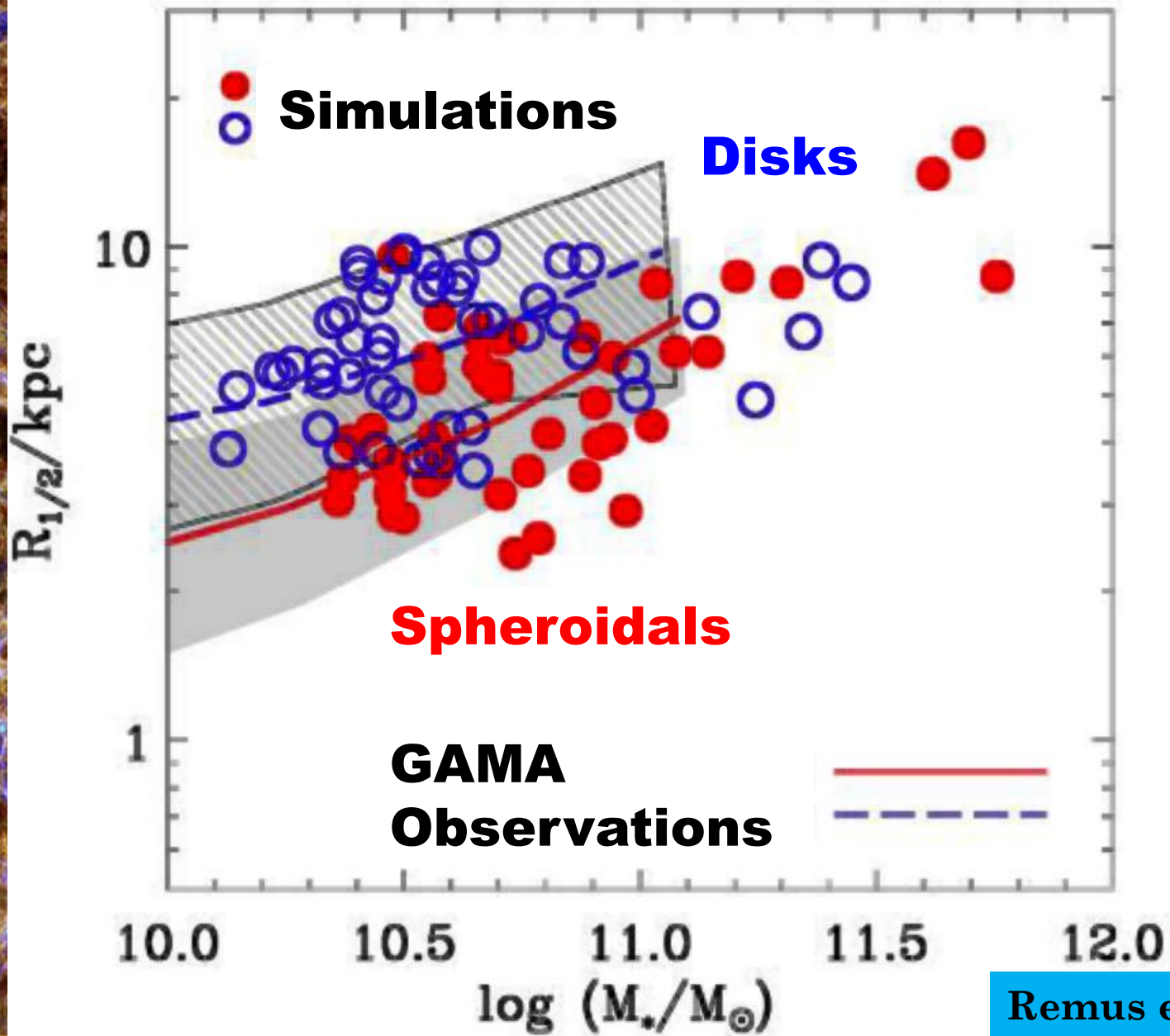


Holds even for the DM only simulation !

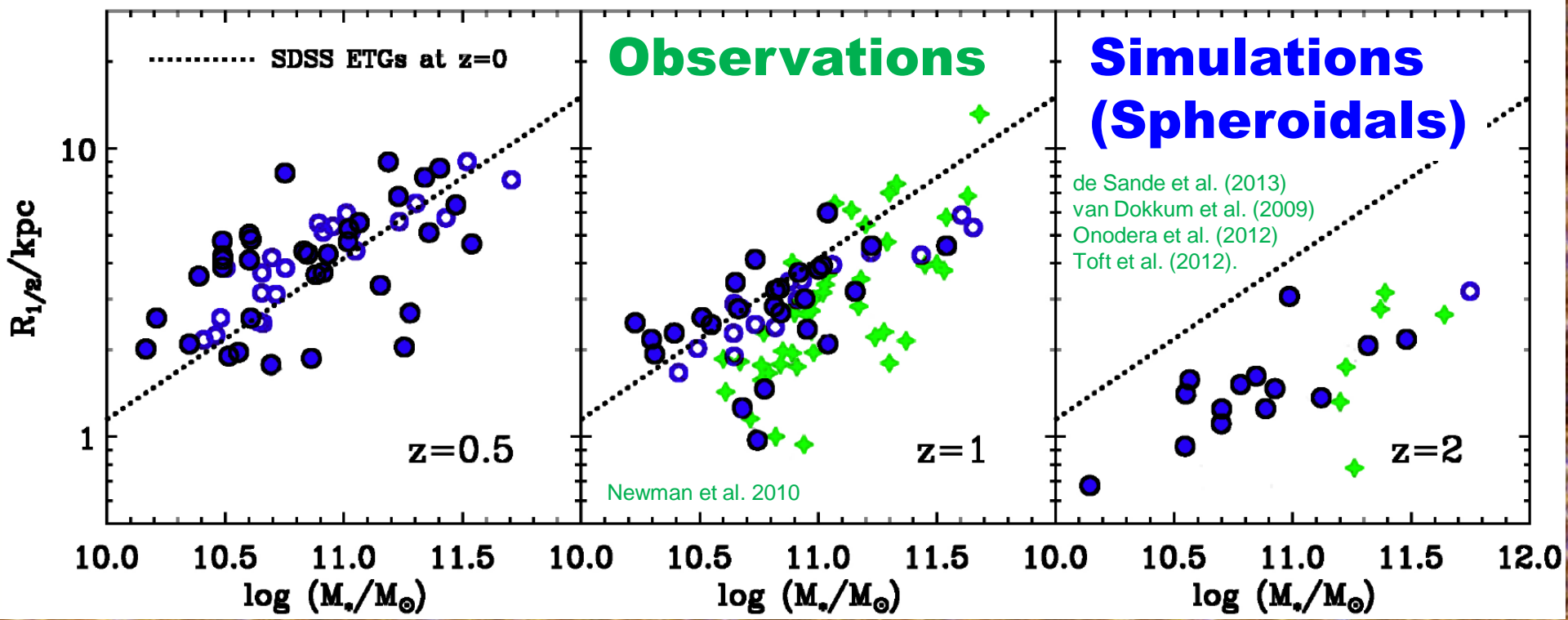
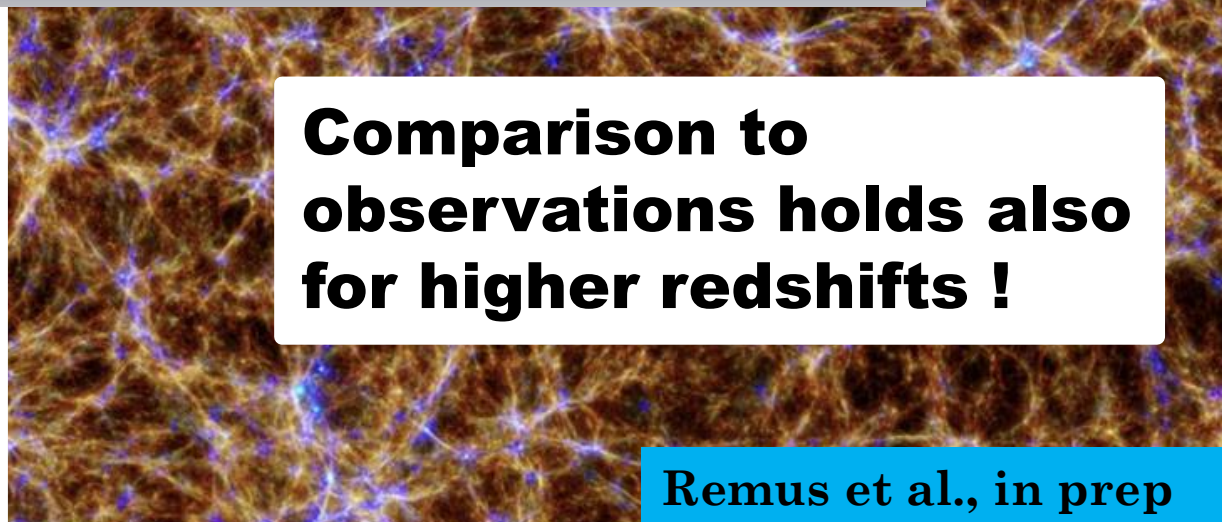
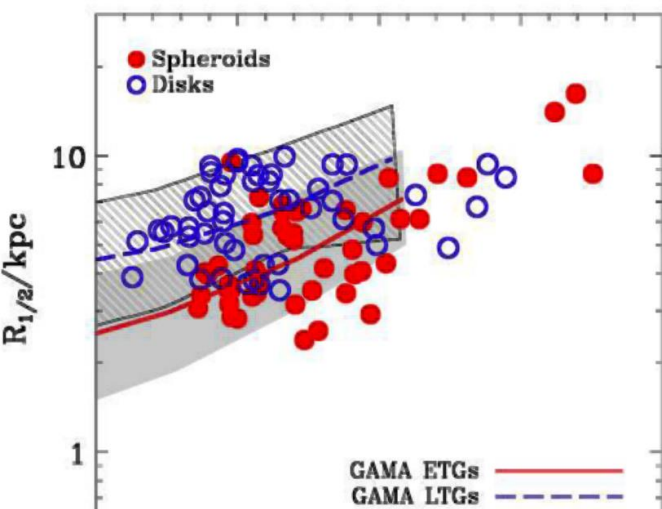
Simulations vs. observations



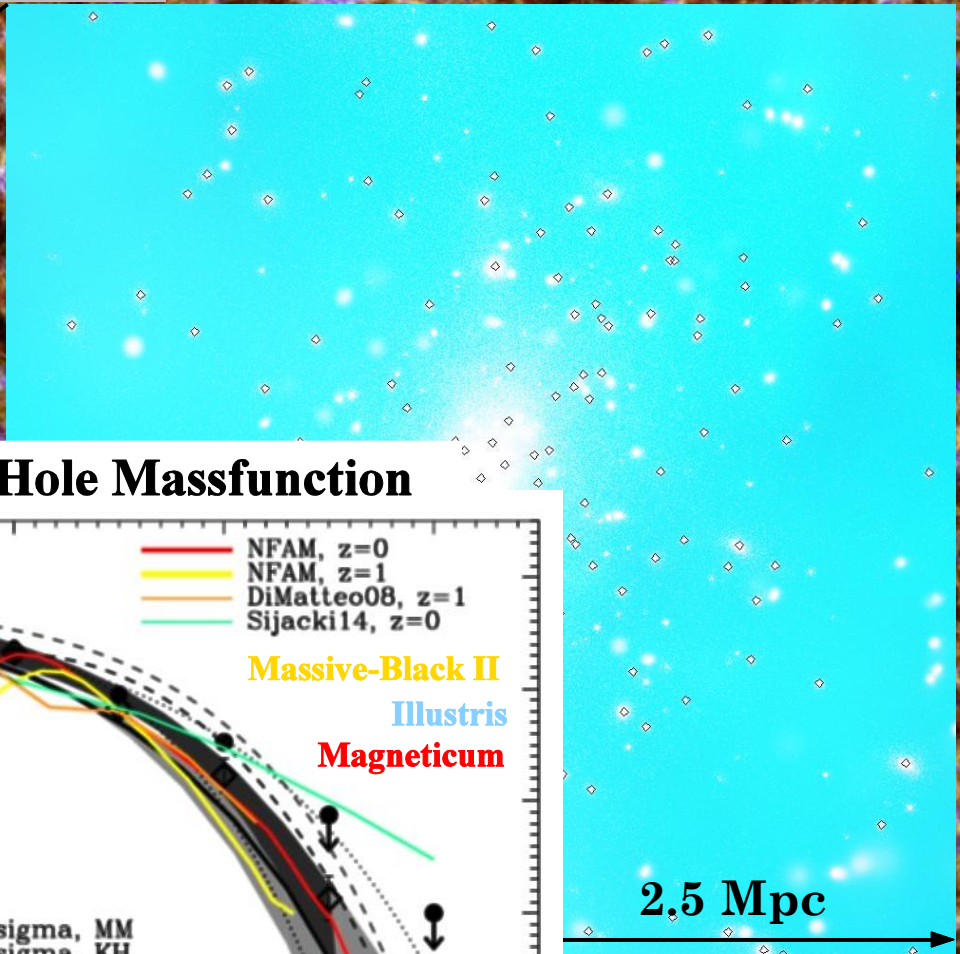
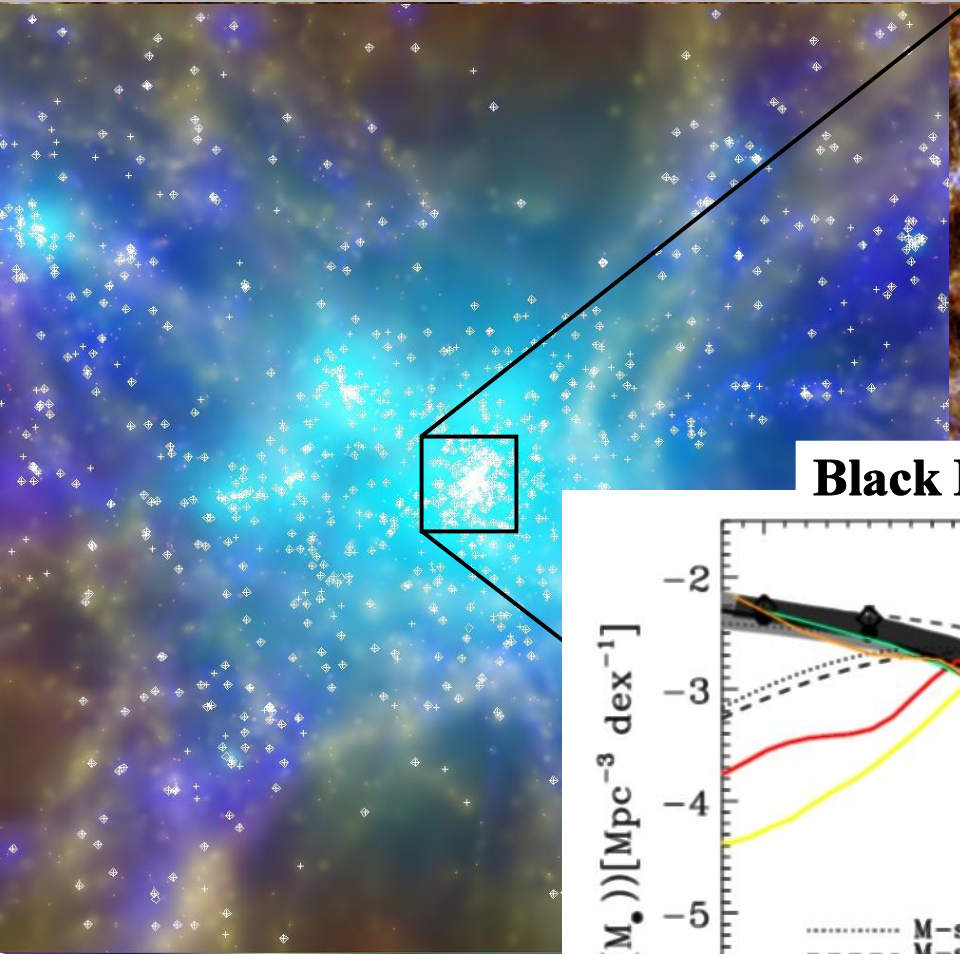
Simulations vs. observations



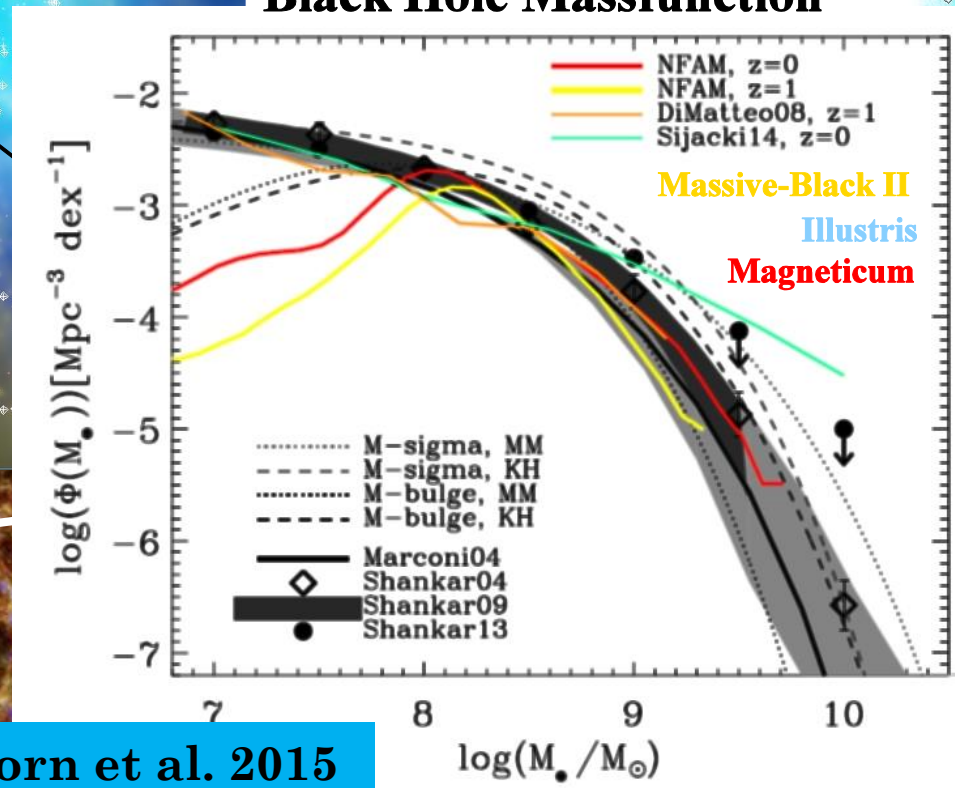
Simulations vs. observations



Black Hole properties

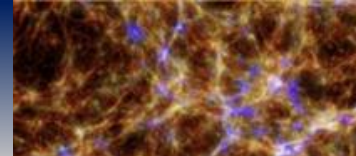


Black Hole Massfunction



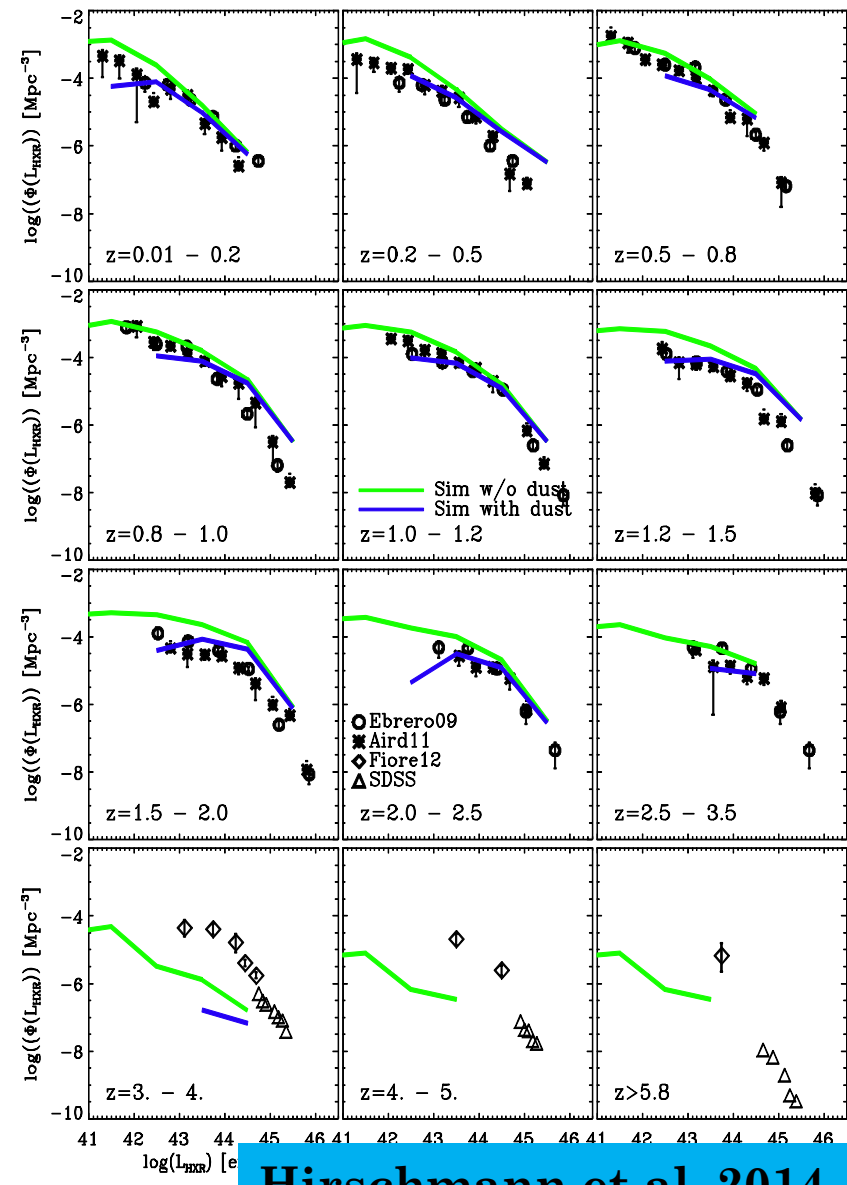
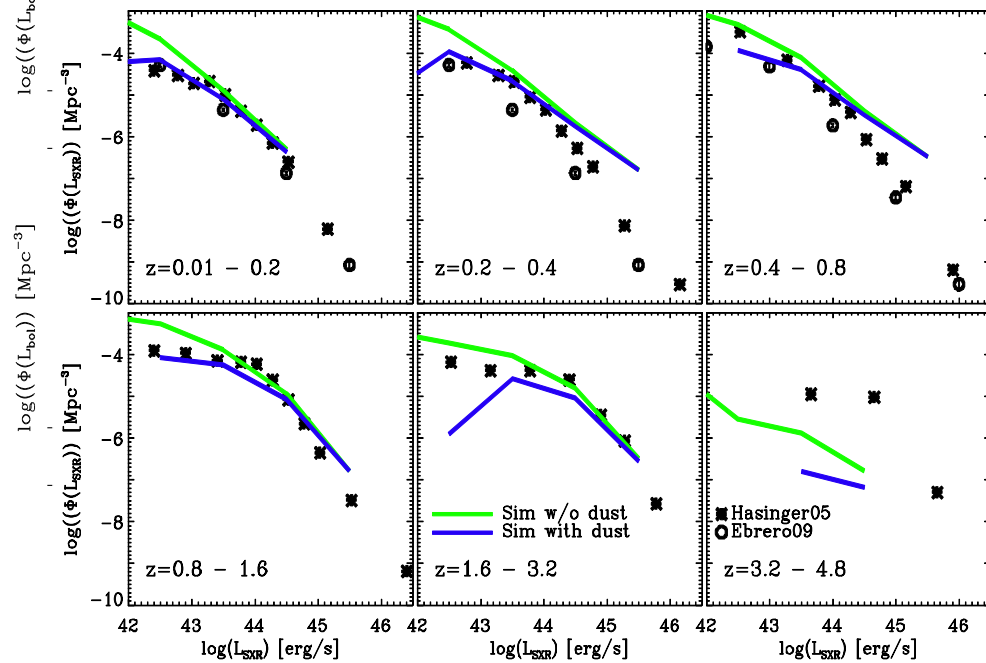
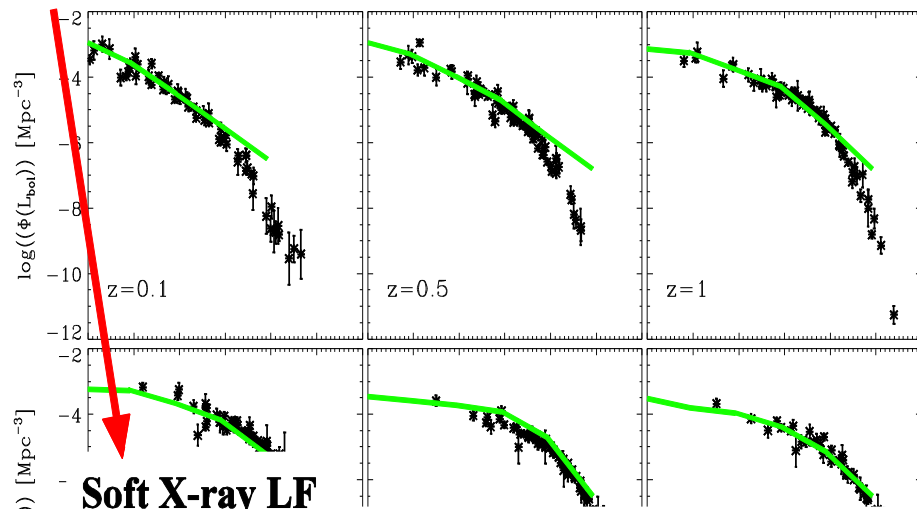
Steinborn et al. 2015

AGN properties (optical + X-ray)

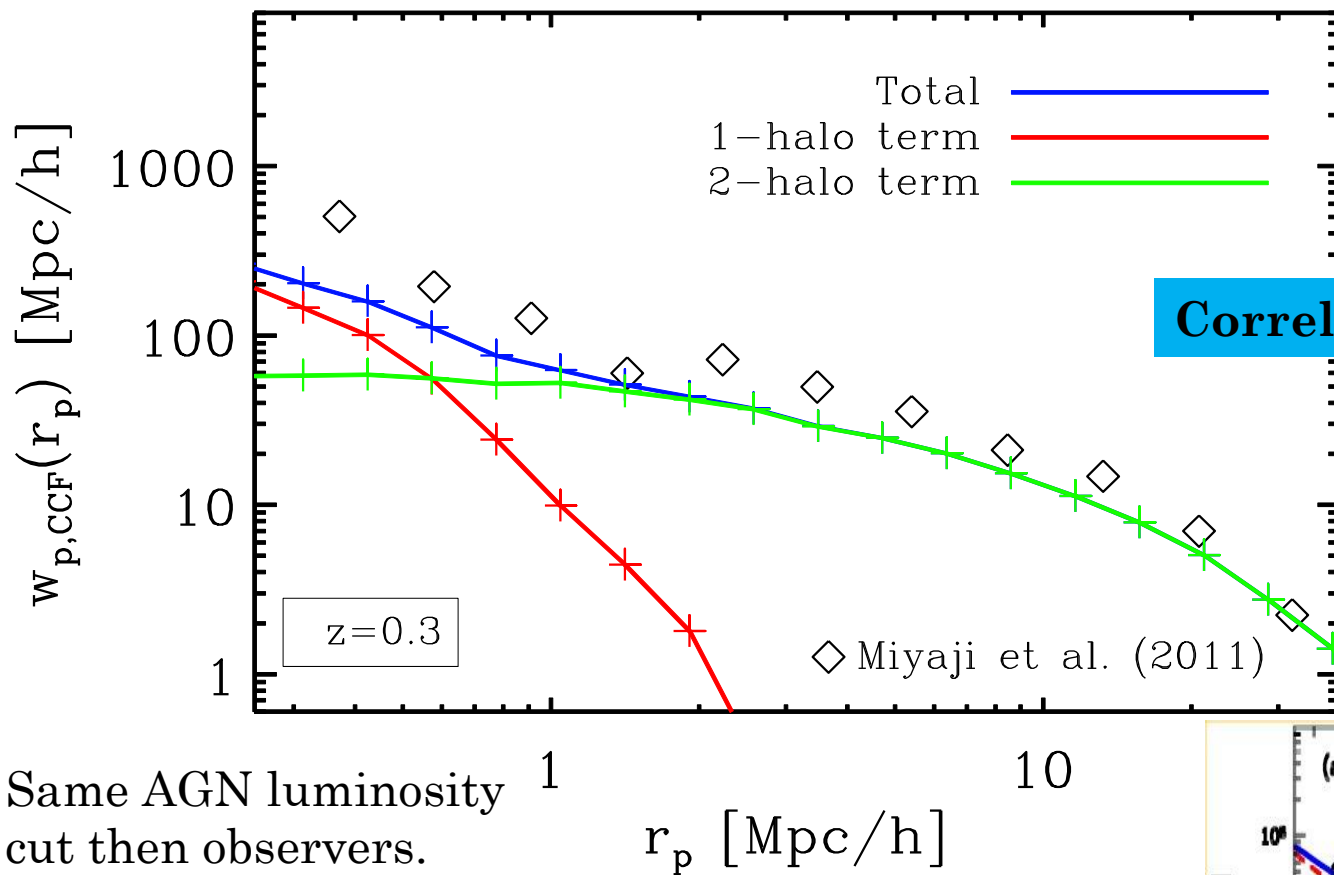


Bolometric LF

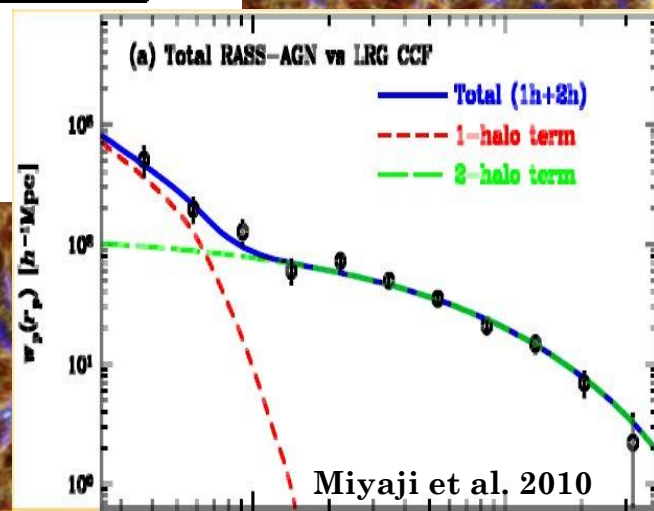
Hard X-ray LF



AGN distribution



Correlation function



Steinborn, in prep.

MAGNETICUM



Conclusions (general)

1) ICM: Clusters well reproduced

pressure profiles, SZ powerspectrum, Cluster counts, **no tension with CMB cosmology !**

2) Galaxies: Dynamics well reproduced

spin, morphologies, colors, mass-size relation

3) Black holes: Observations well reproduced

mass functions, luminosity functions, correlation functions, AGN-host connections

4) Universality in outer halos

from galaxies to clusters, not directly related to morphology, reflecting recent dynamical activity

More into details (future)

1) Large volumes for Planck/eROSITA

for the first time, hydro-dynamical simulations cover large volumes and „enough“ physical processes

2) ICM/AGN constrain sub-grid models

combination of observables from ICM, AGNs (and galaxies) start to constrain our sub-grid models