The Magneticum Simulations, from Galaxies to Galaxy Clusters

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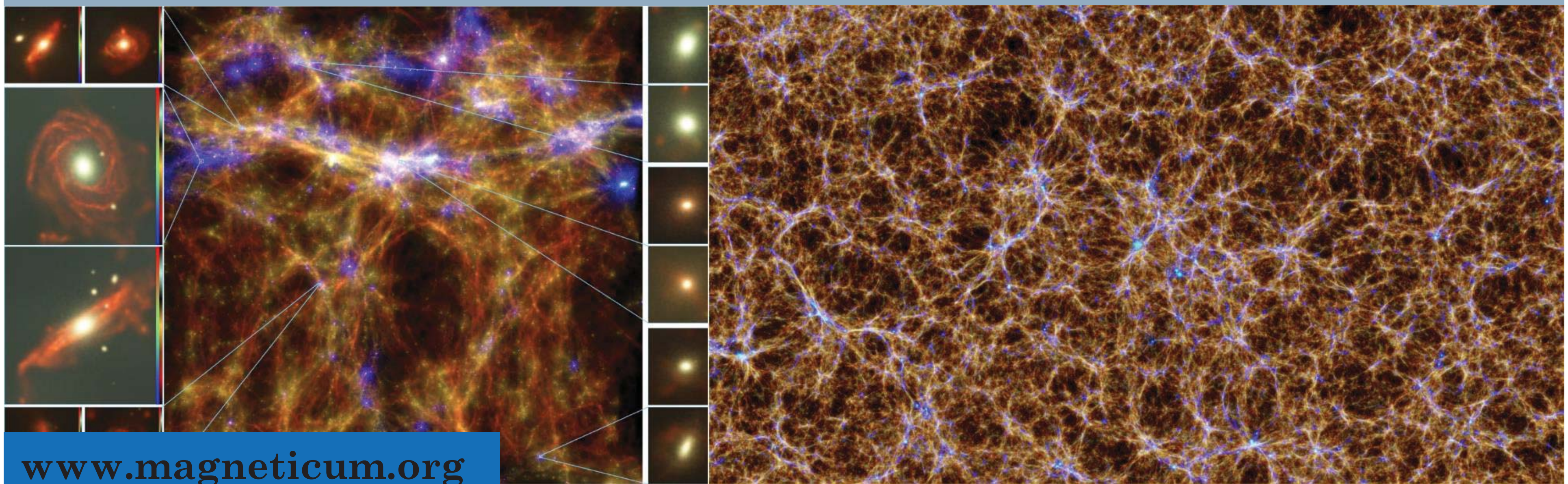
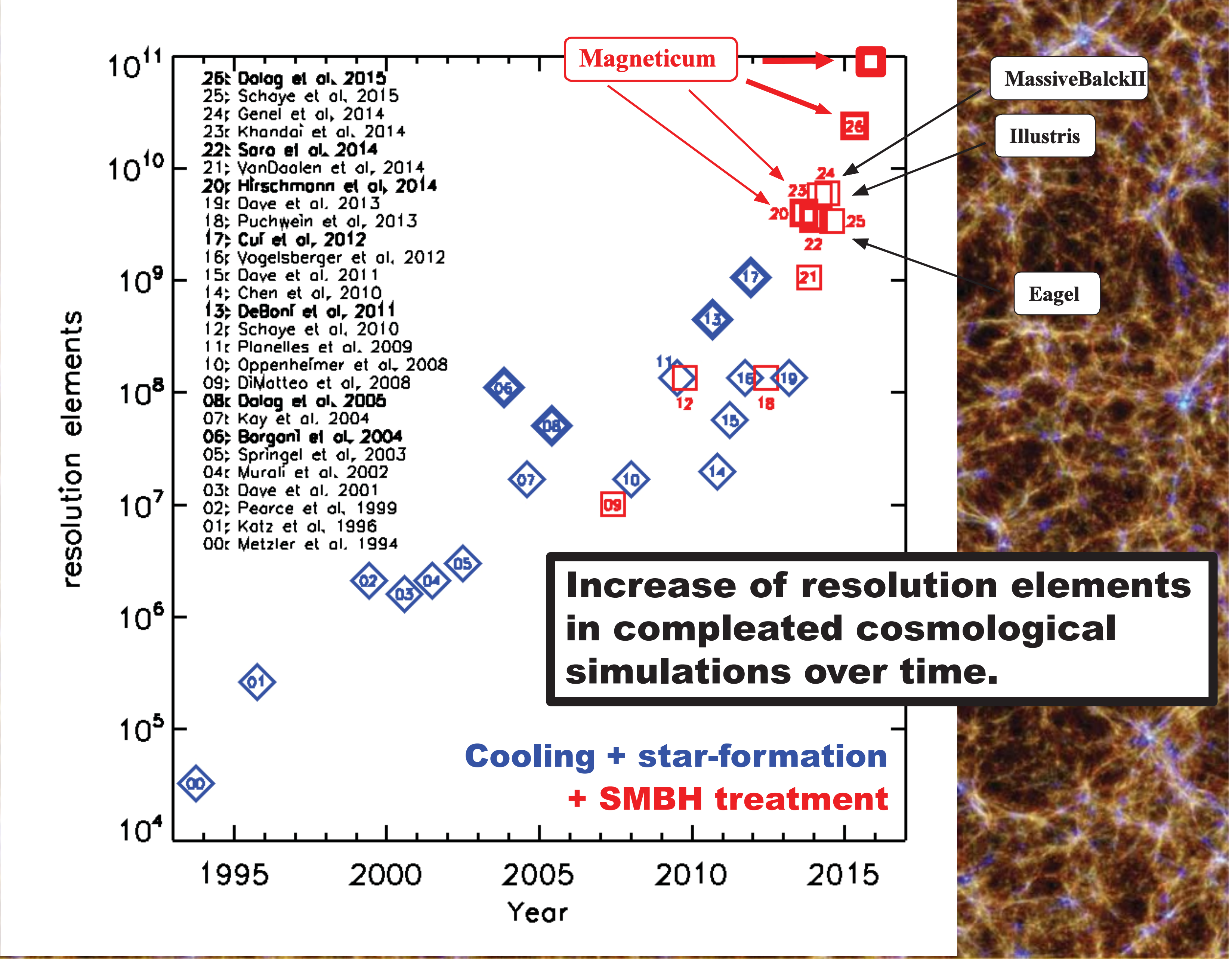
MAGNETICUM

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



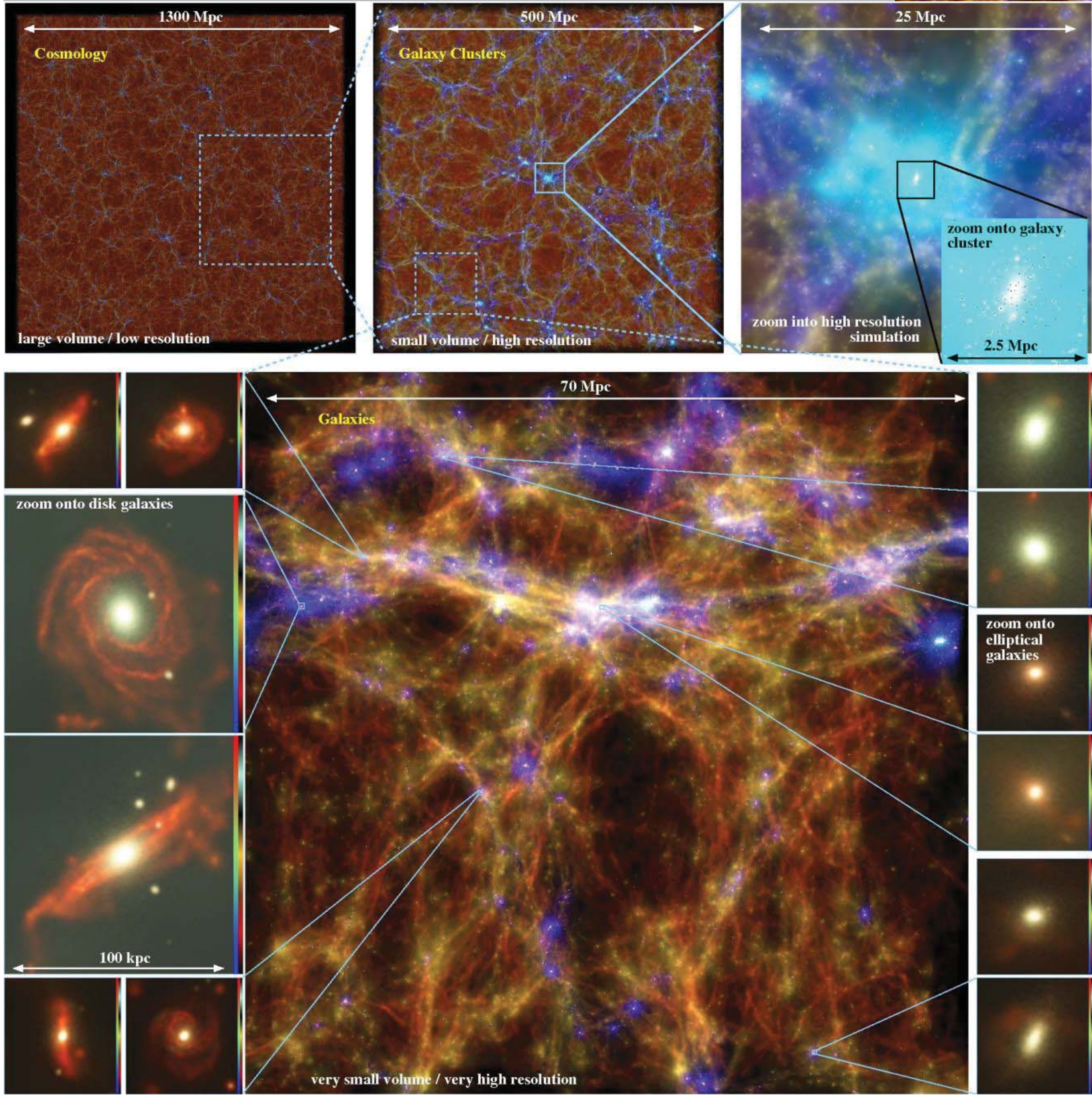
www.magneticum.org

What we reached so far



Increase of resolution elements in compleated cosmological simulations over time.

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

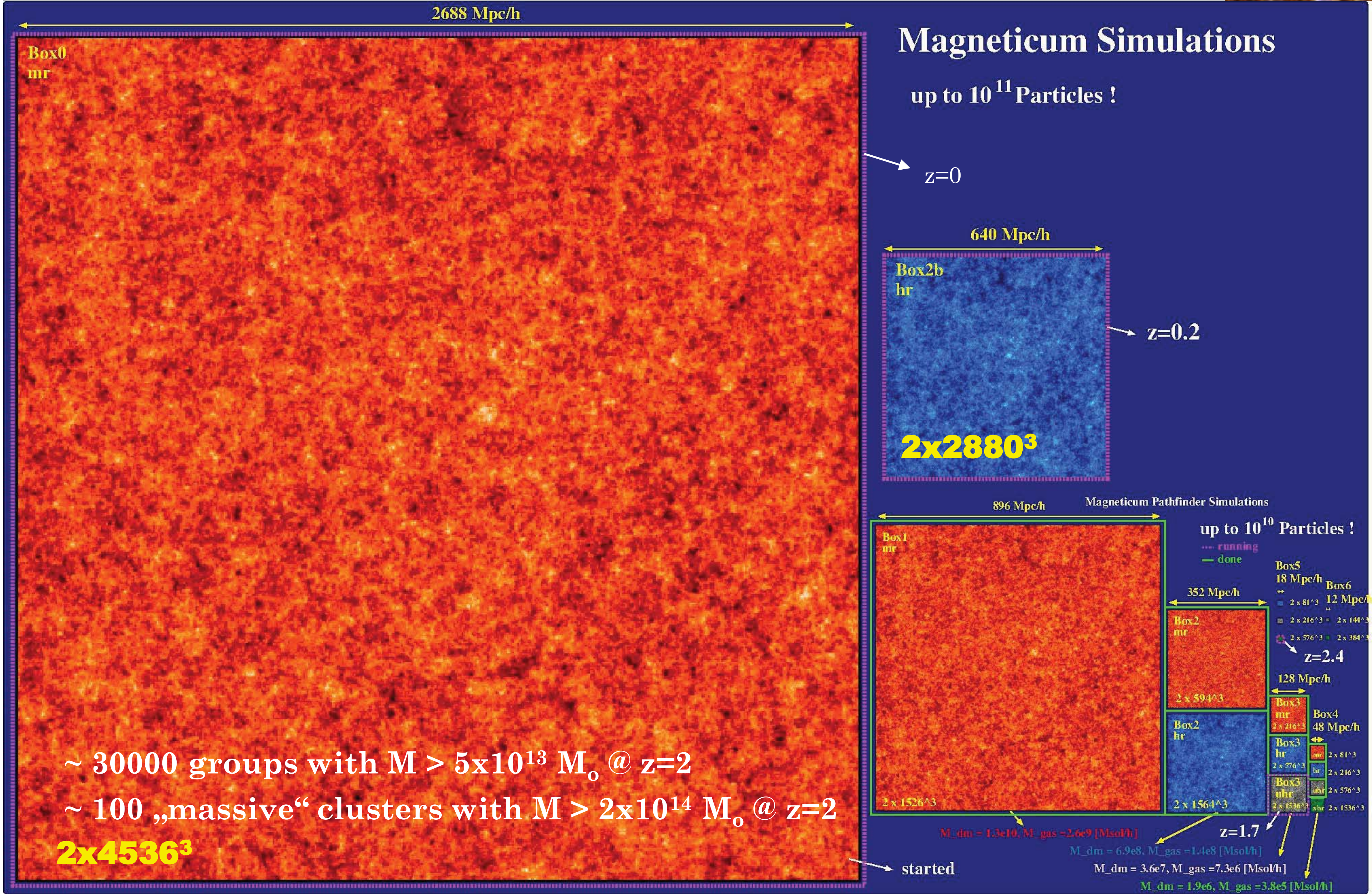
mr/hr (time dep. alpha)

Dolag et al. 2005

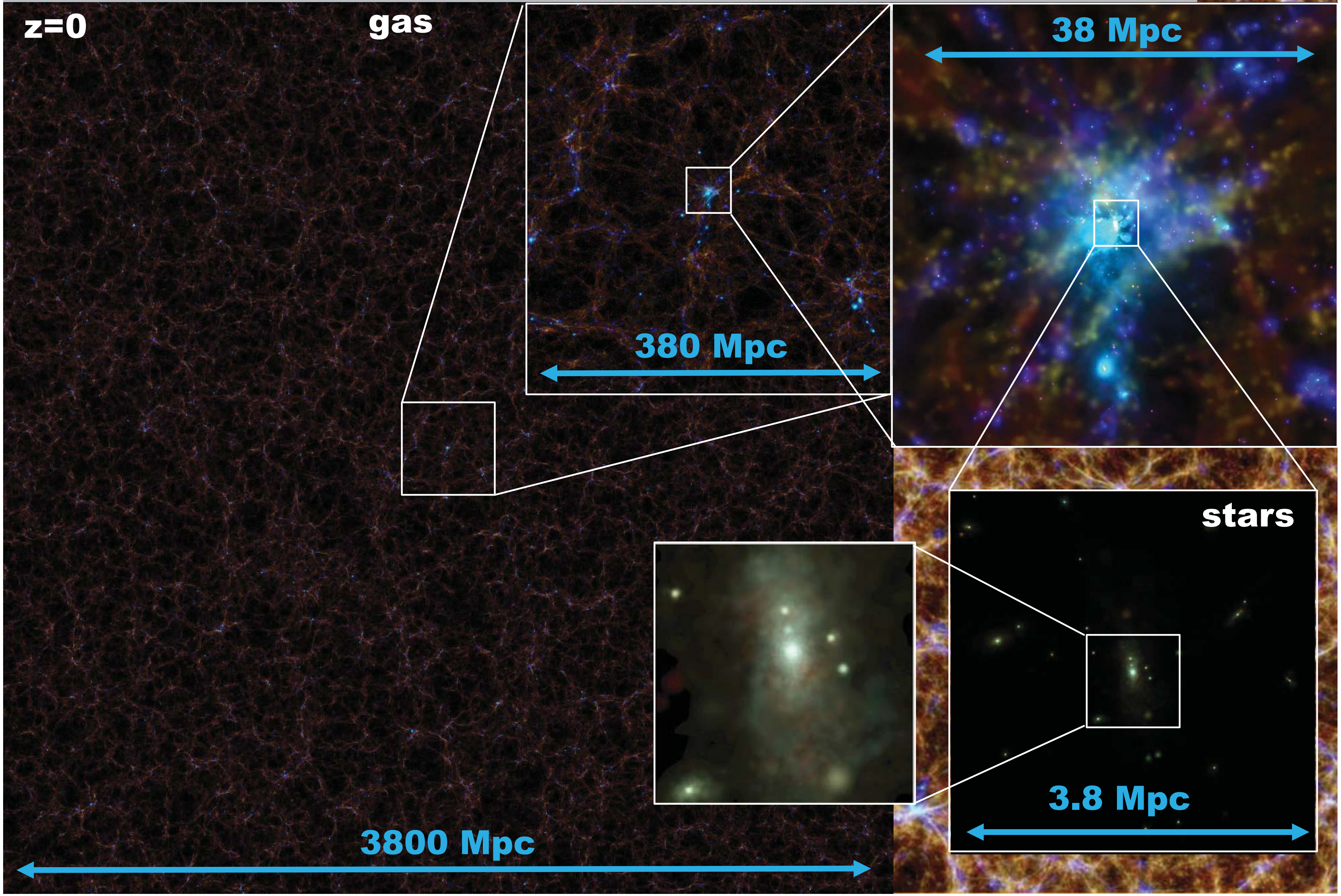
uhr (high order grad.)

Beck et al. 2015

The Magneticum Simulations



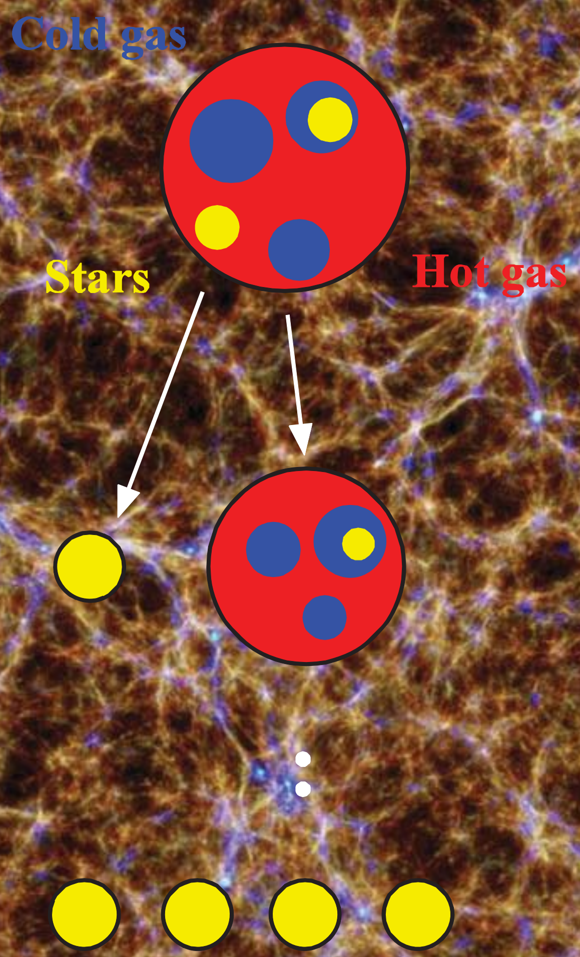
Largest Simulation (Box0/mr)



Sub-resolution star-formation:

Multi phase model (sub-scale)

Springel & Hernquist 2002



Star formation

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

supernova mass fraction (β)

star formation timescale ($t_\star$)

Cloud evaporation

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

cloud evaporation parameter (A)

Growth of clouds

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

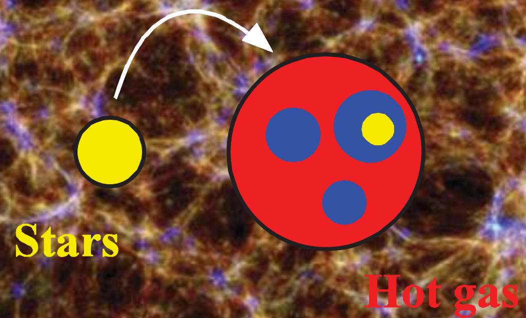
cooling function ($\Lambda_{\rm net}$)

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



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, ...

star-formation rate

fraction of stars in binary systems

SNIa rate:

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

distribution of mass-ratios in binary systems

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

SNII and AGB rate:

$$R_{\rm SN\,II|ILMS}(t) = \phi(m(t)) \times \left(-\frac{{\rm d}m(t)}{{\rm d}t}\right)$$

Initial mass function (IMF):

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

Life-time of stars

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

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 (Springl & 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

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

gas density

sound speed

$$\dot{M}_\bullet = \min(\dot{M}_{\rm B}, \dot{M}_{\rm Edd})$$

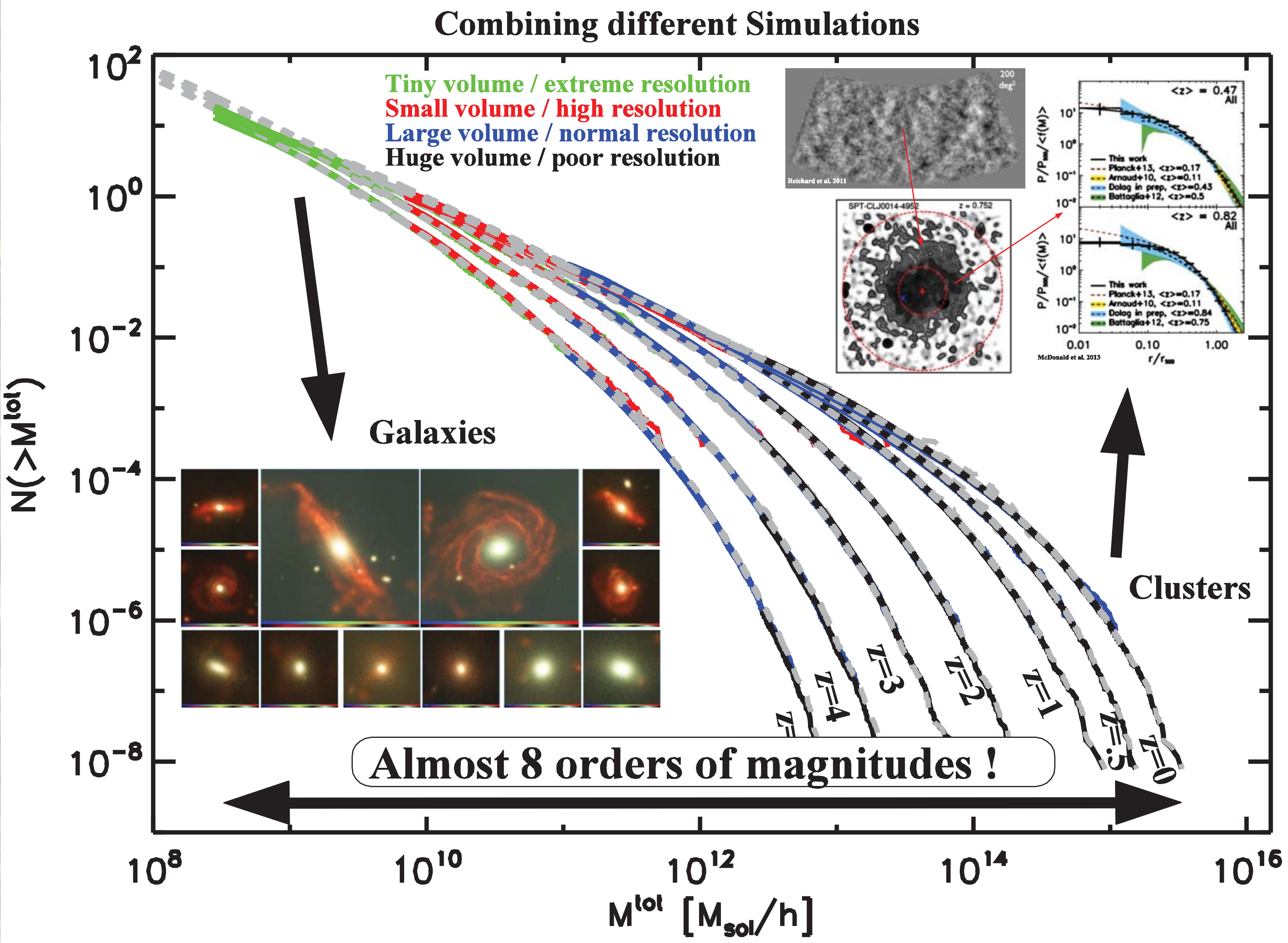
Feedback by Black Holes

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

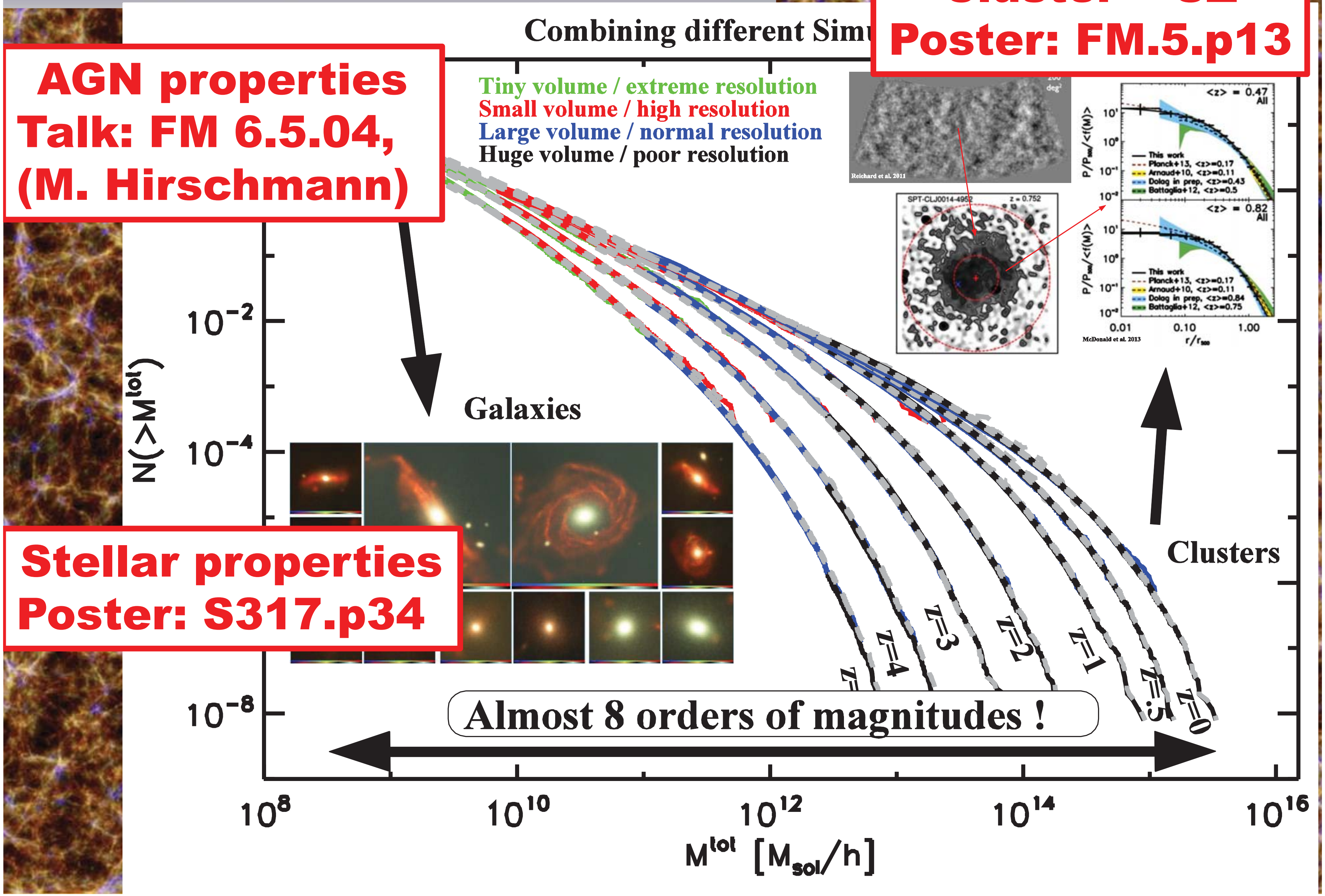
$$\dot{E}_{\rm feedback} = f \times L_{\rm bol}$$

efficiency

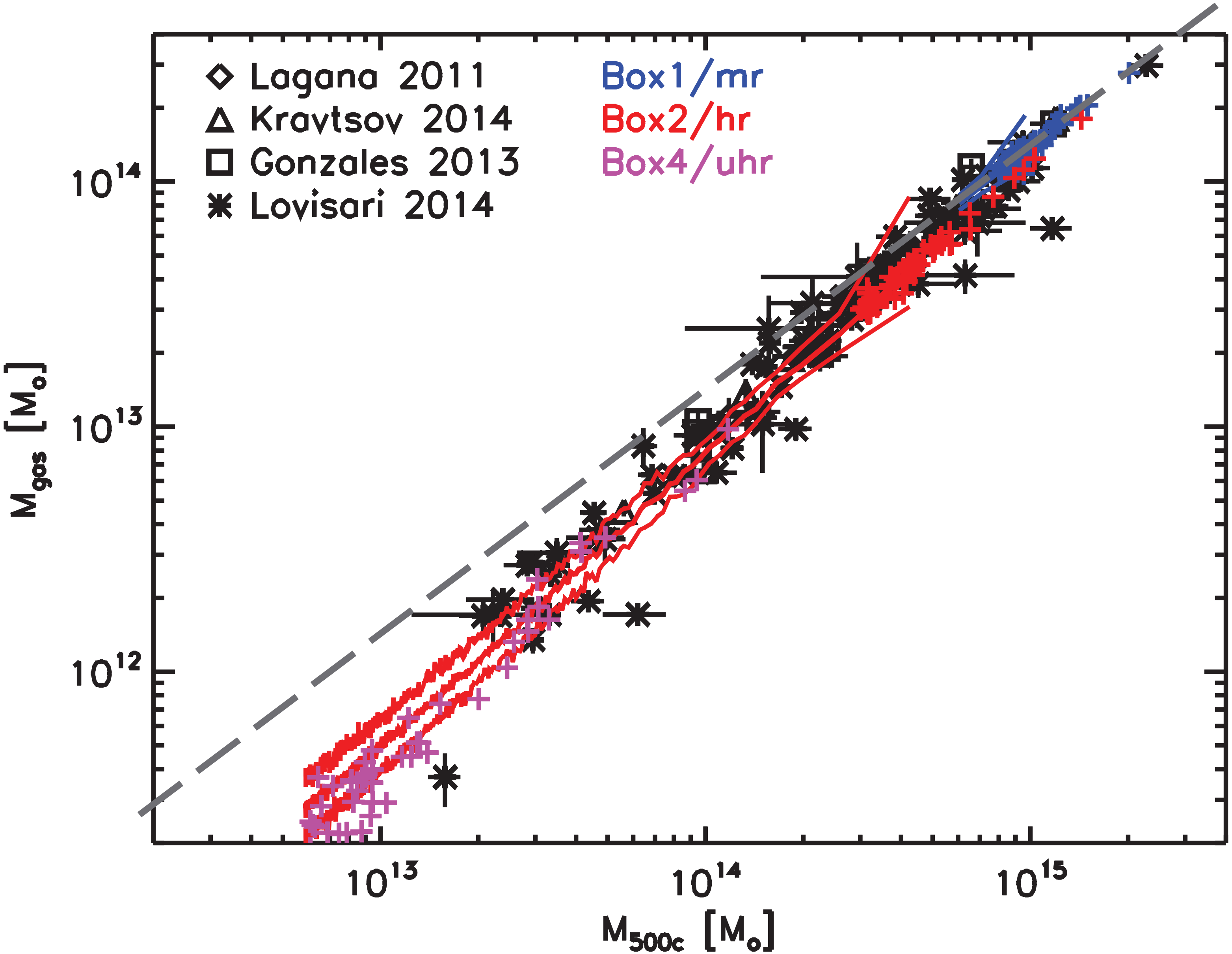
What can we do ...



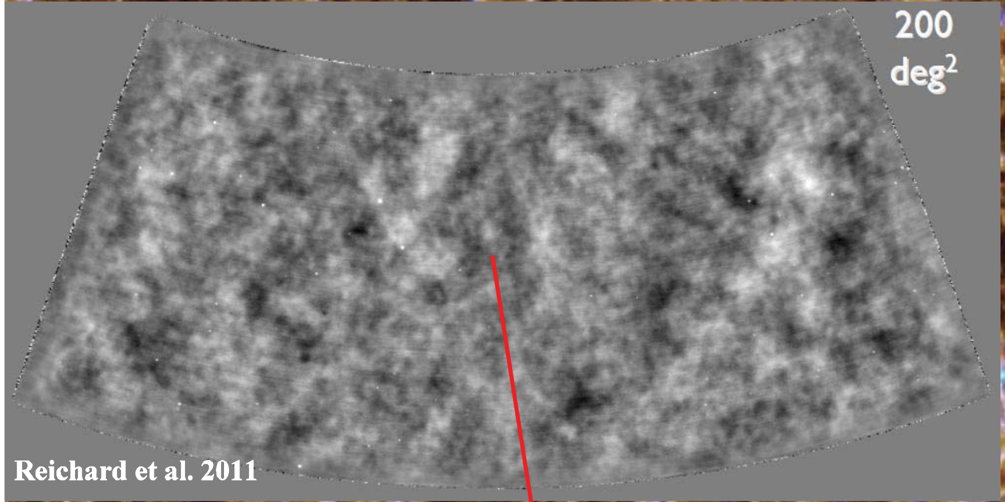
What can we do ...

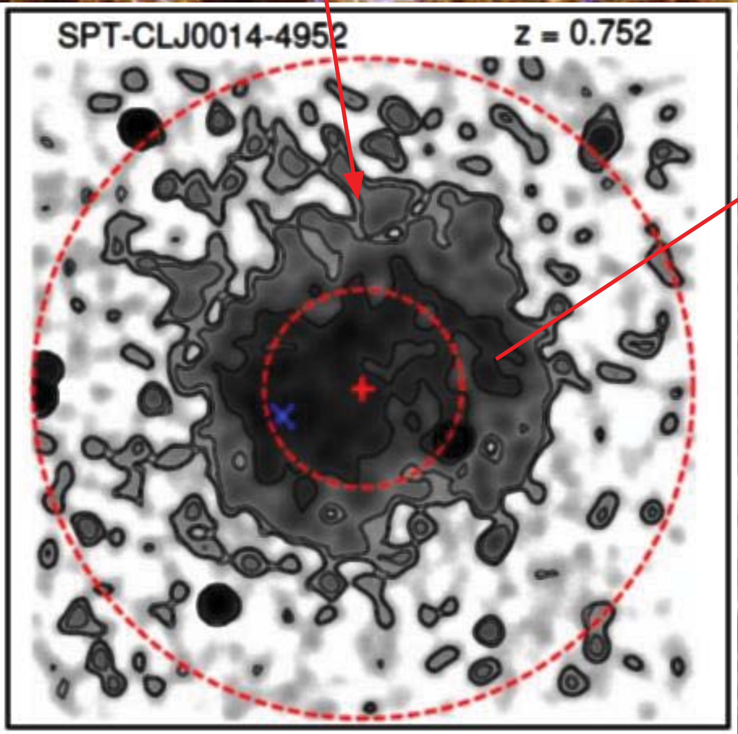


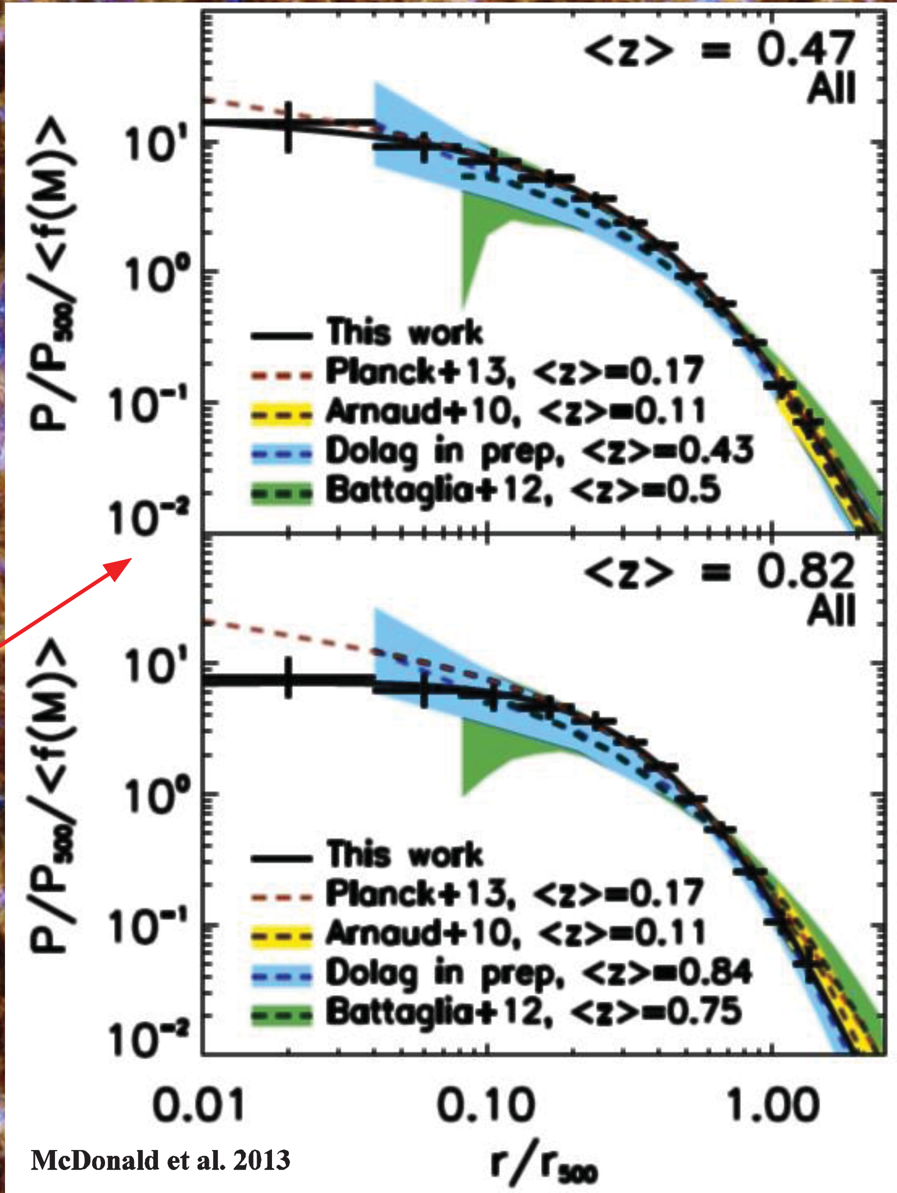
Gas mass of halos



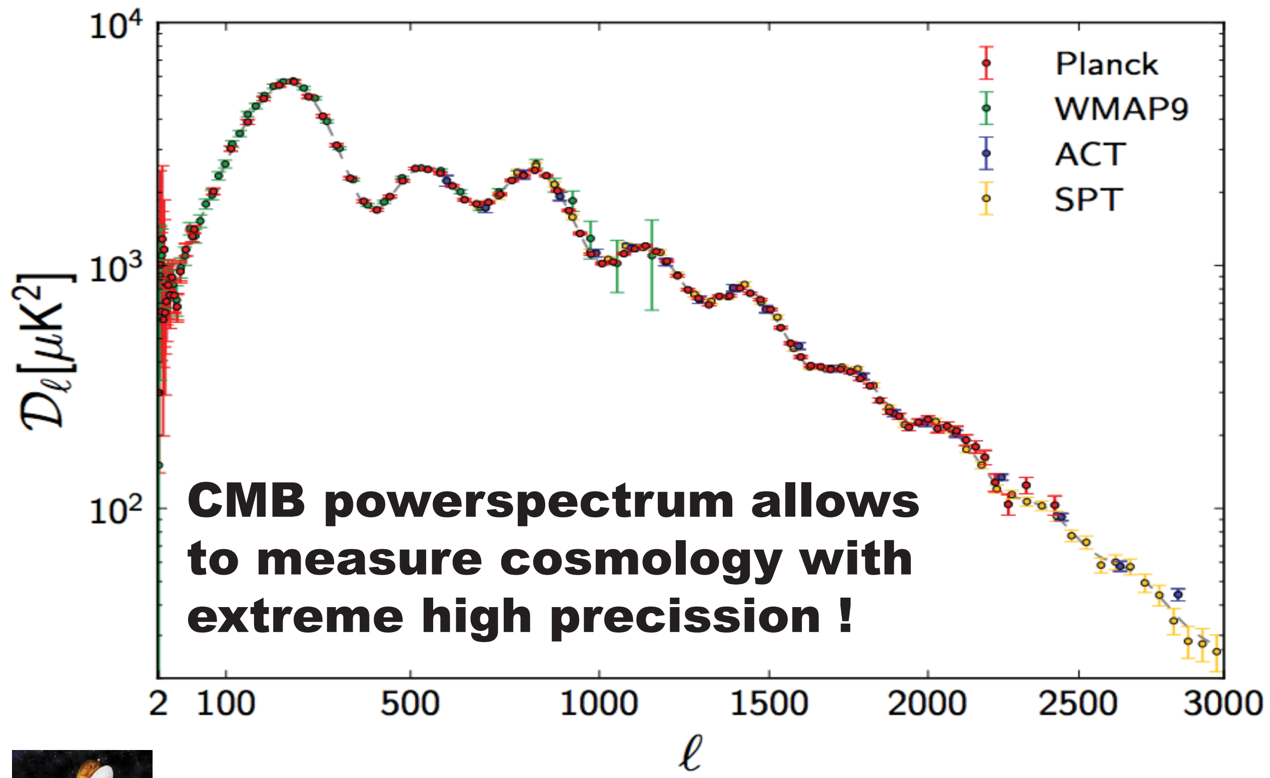
Presssure profiles of clusters

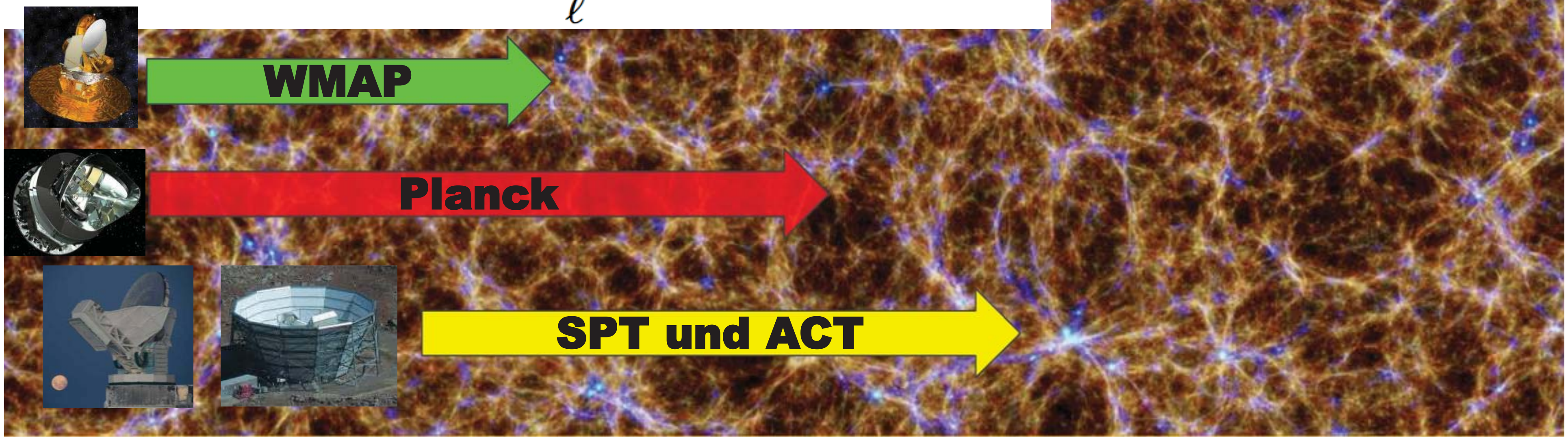






Cluster Cosmology and PLANCK ...





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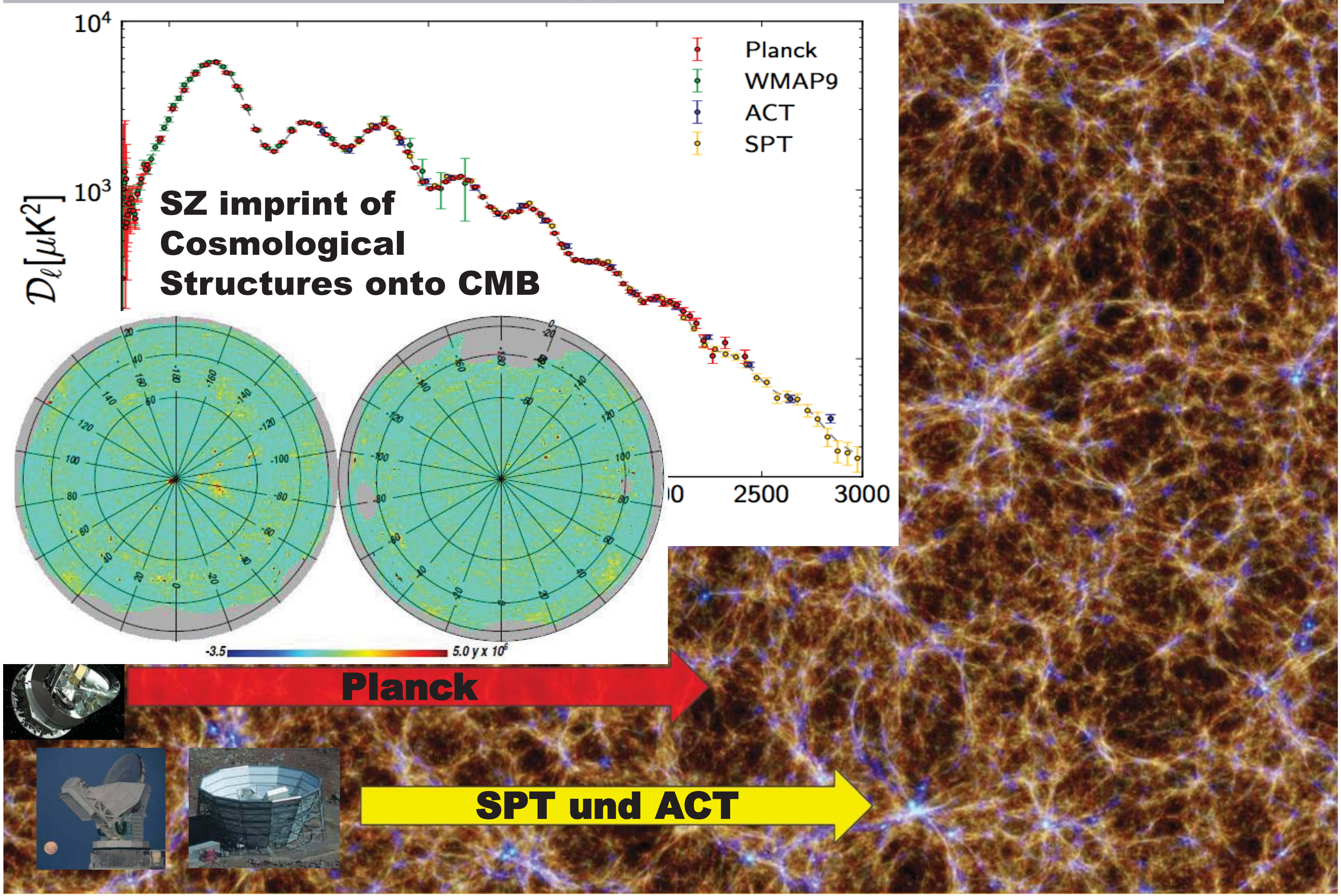

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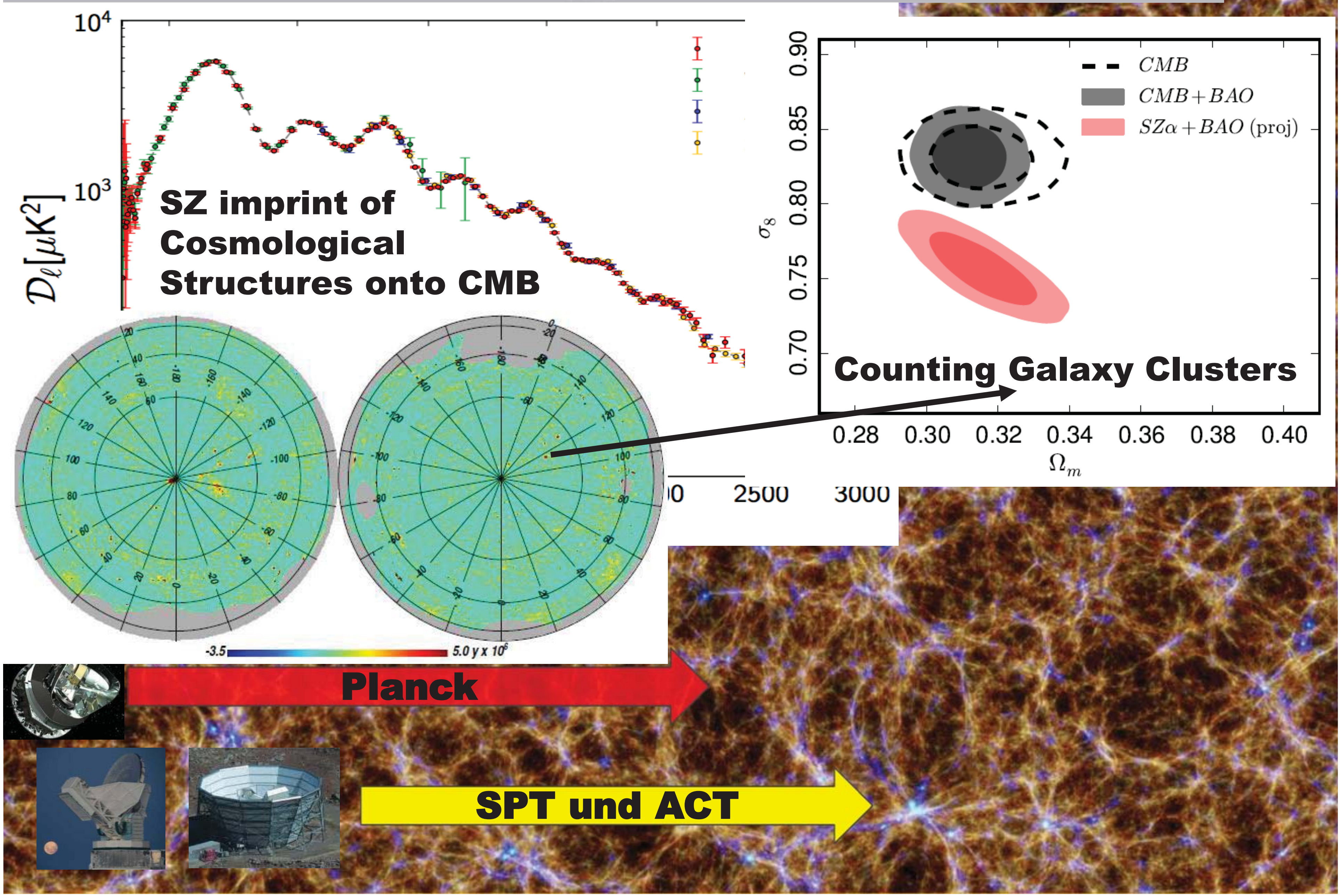

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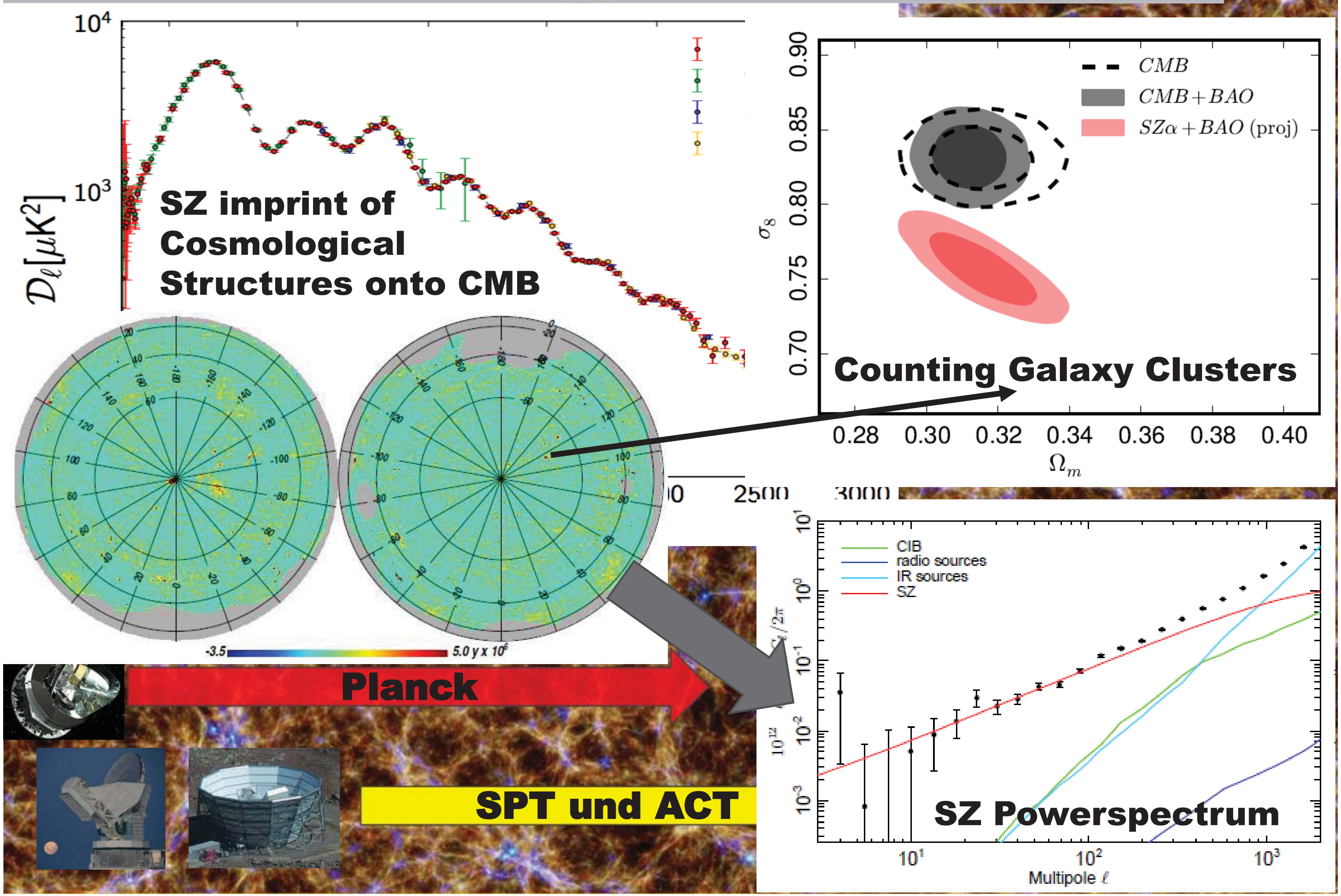

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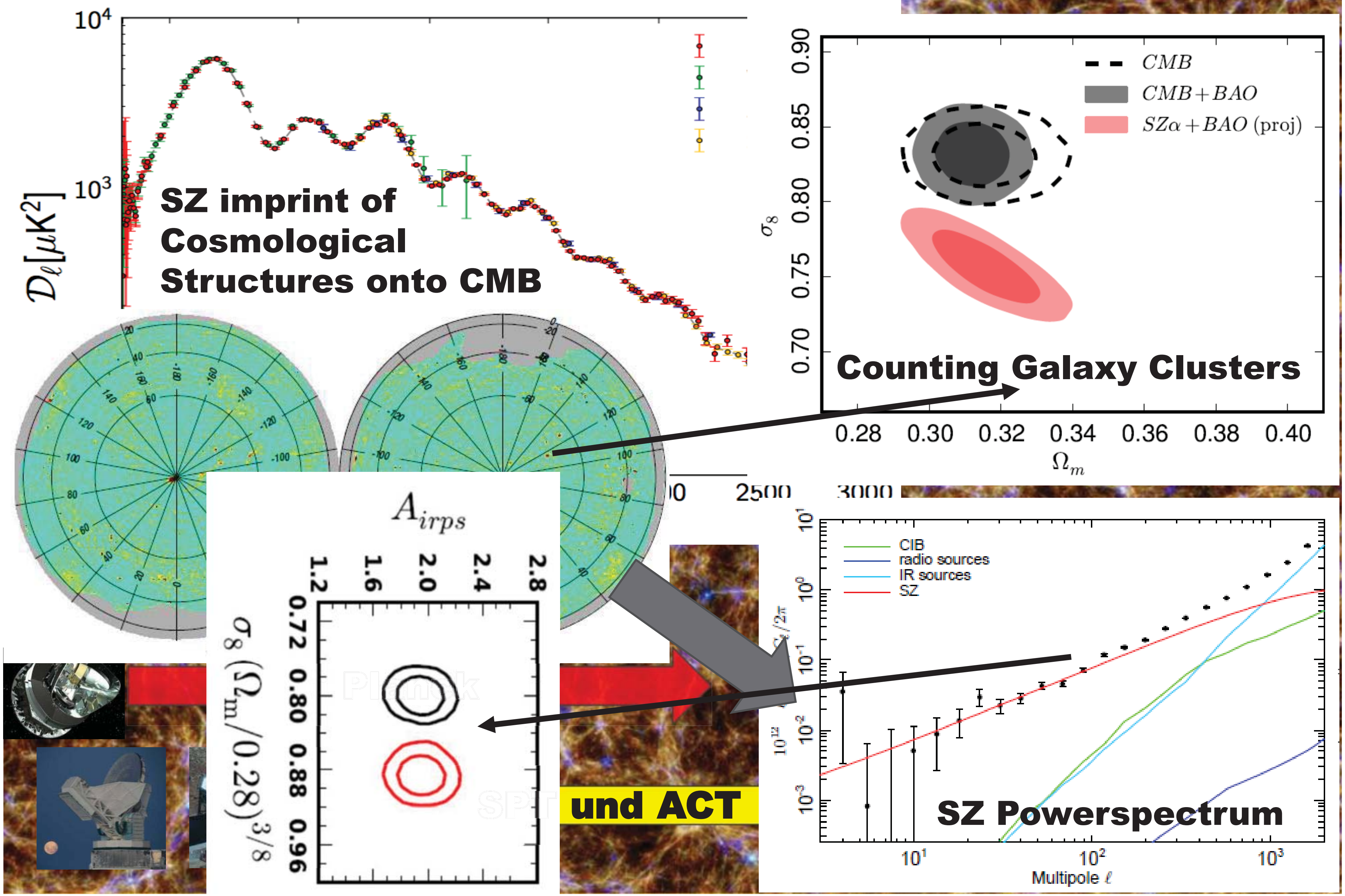
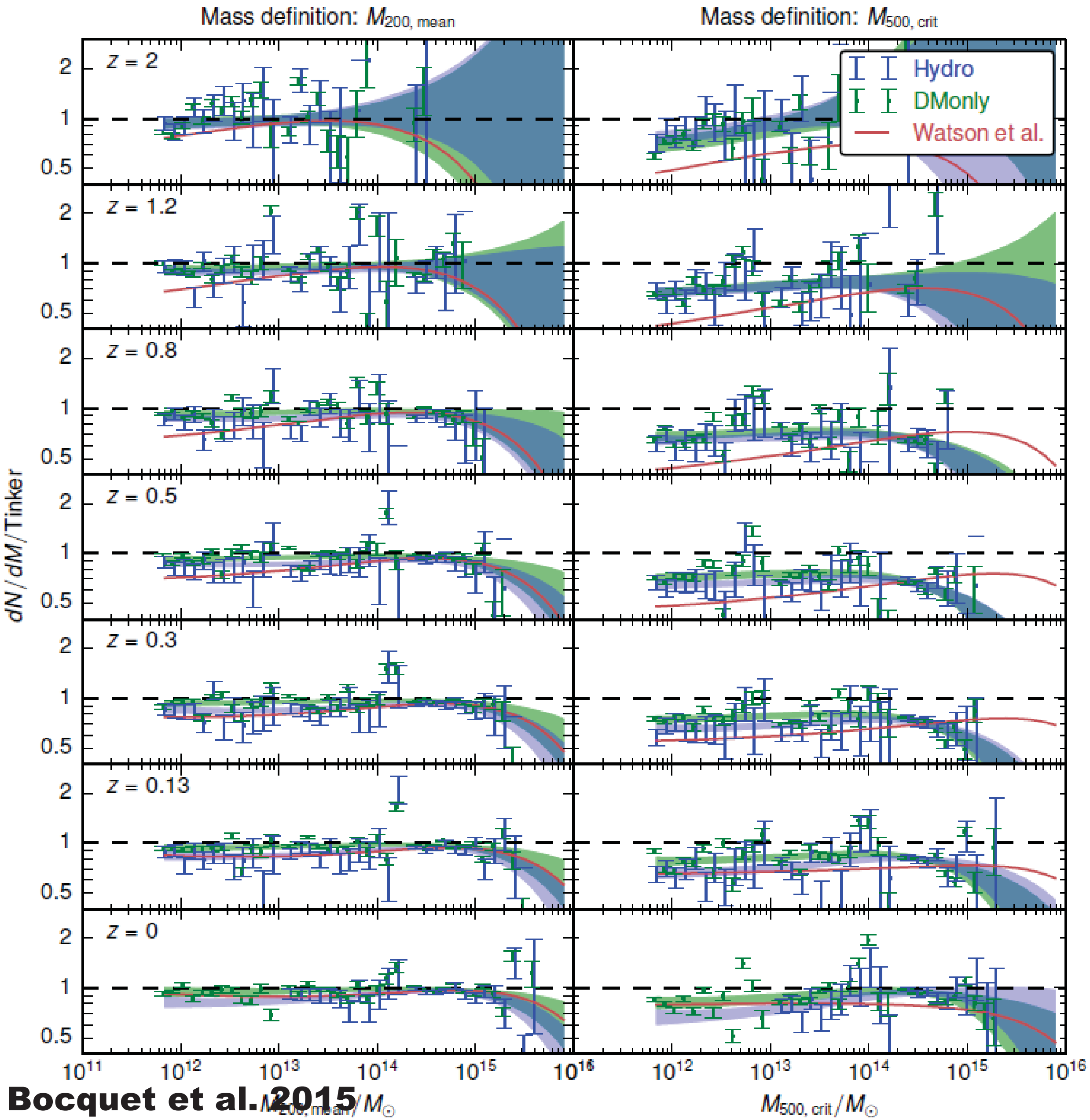
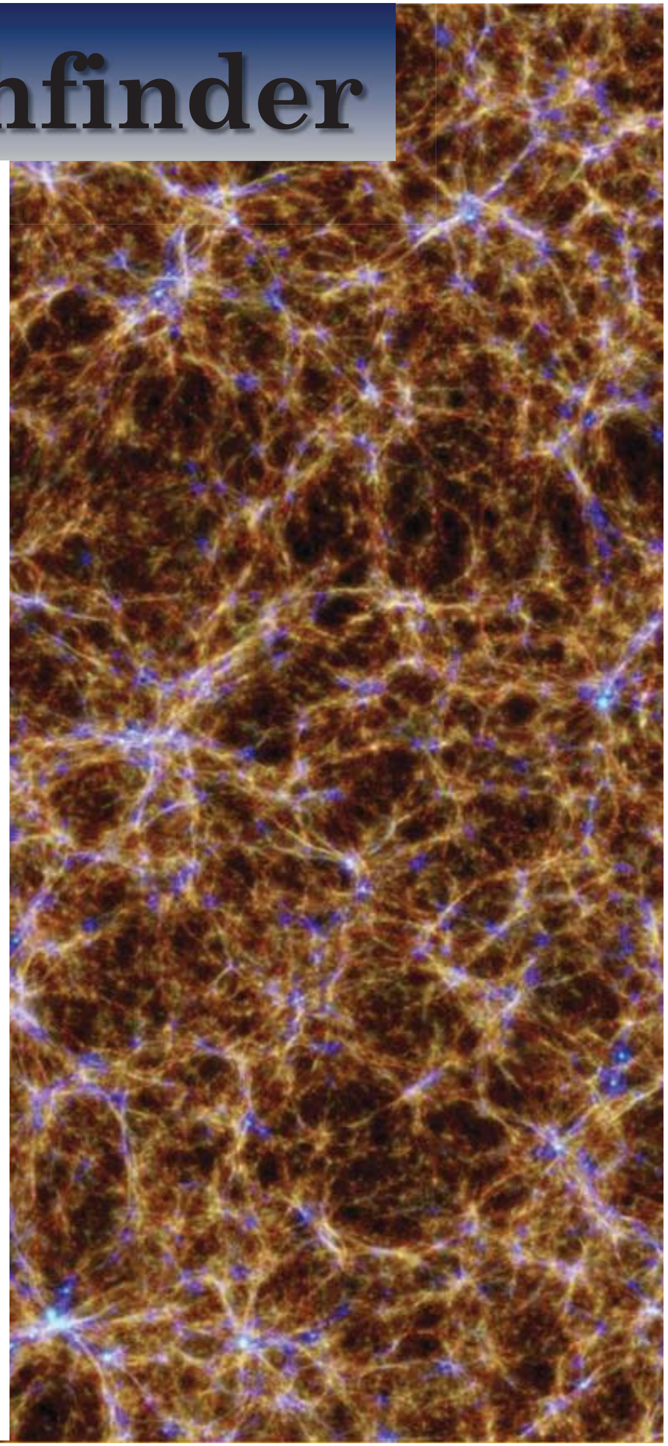


Using Magneticum Pathfinder



Bocquet et al. 2015



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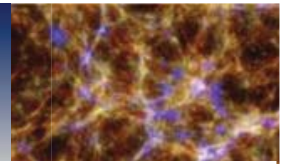
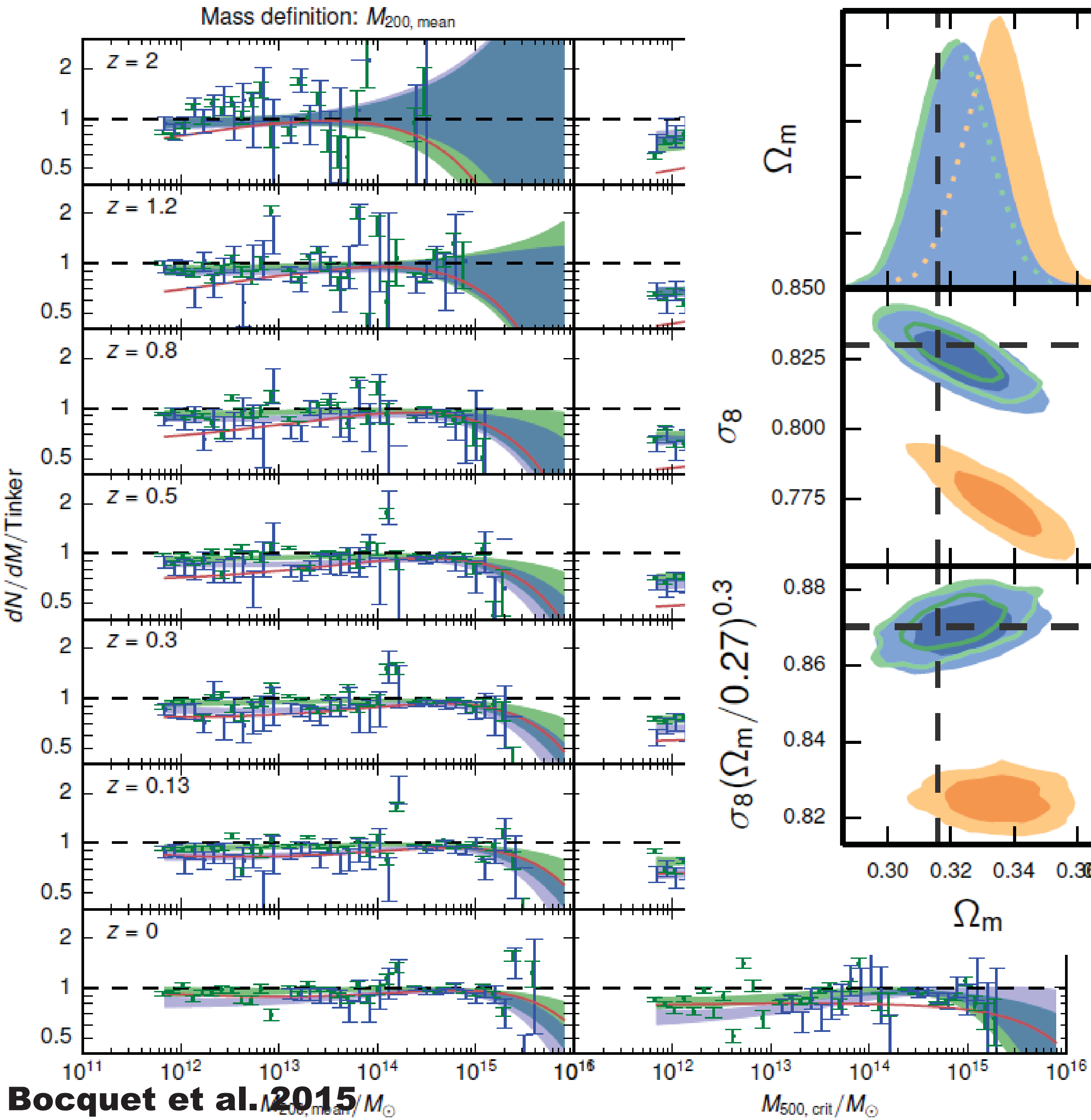
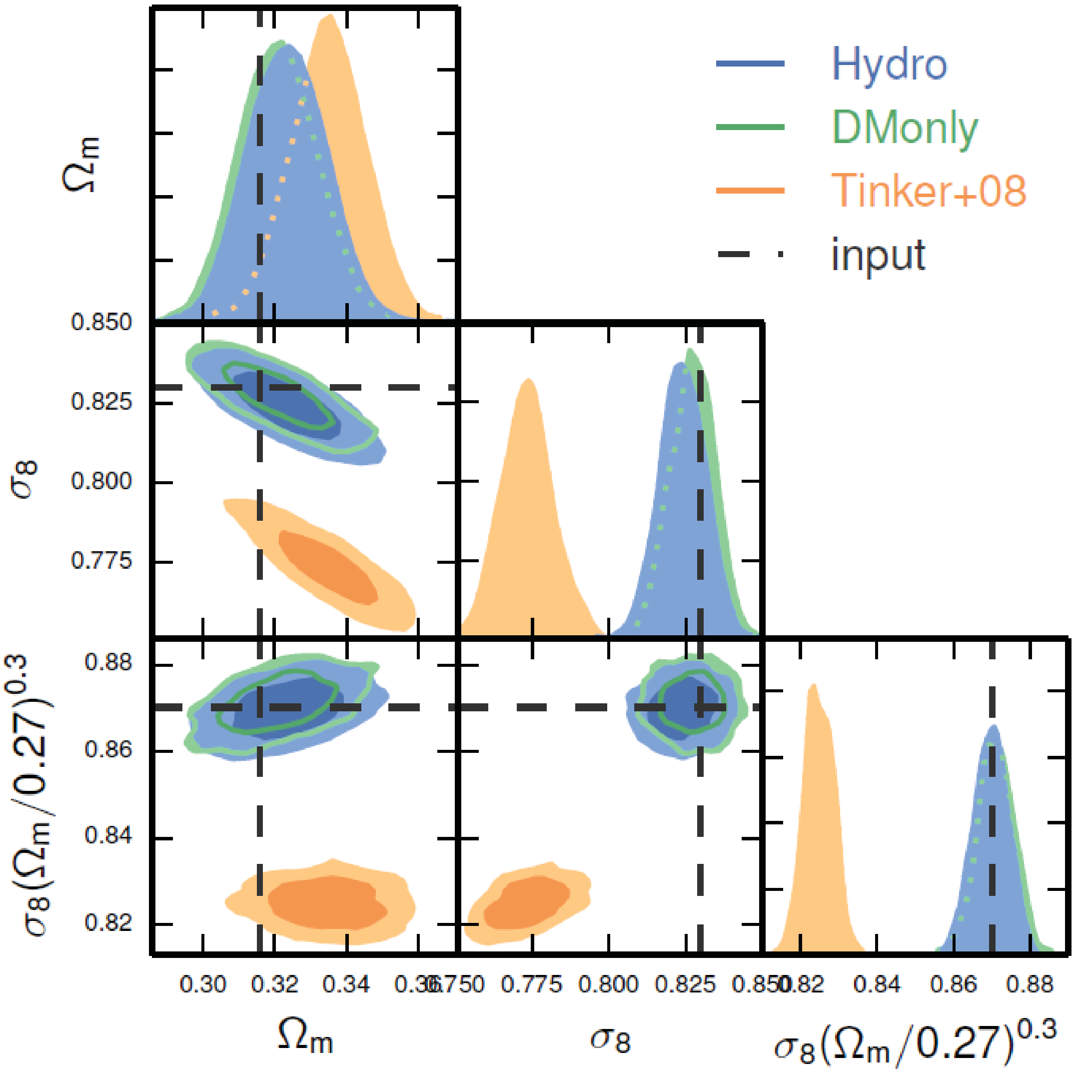
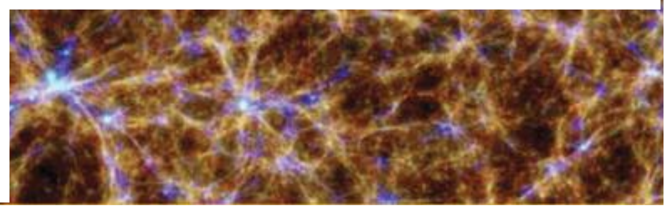


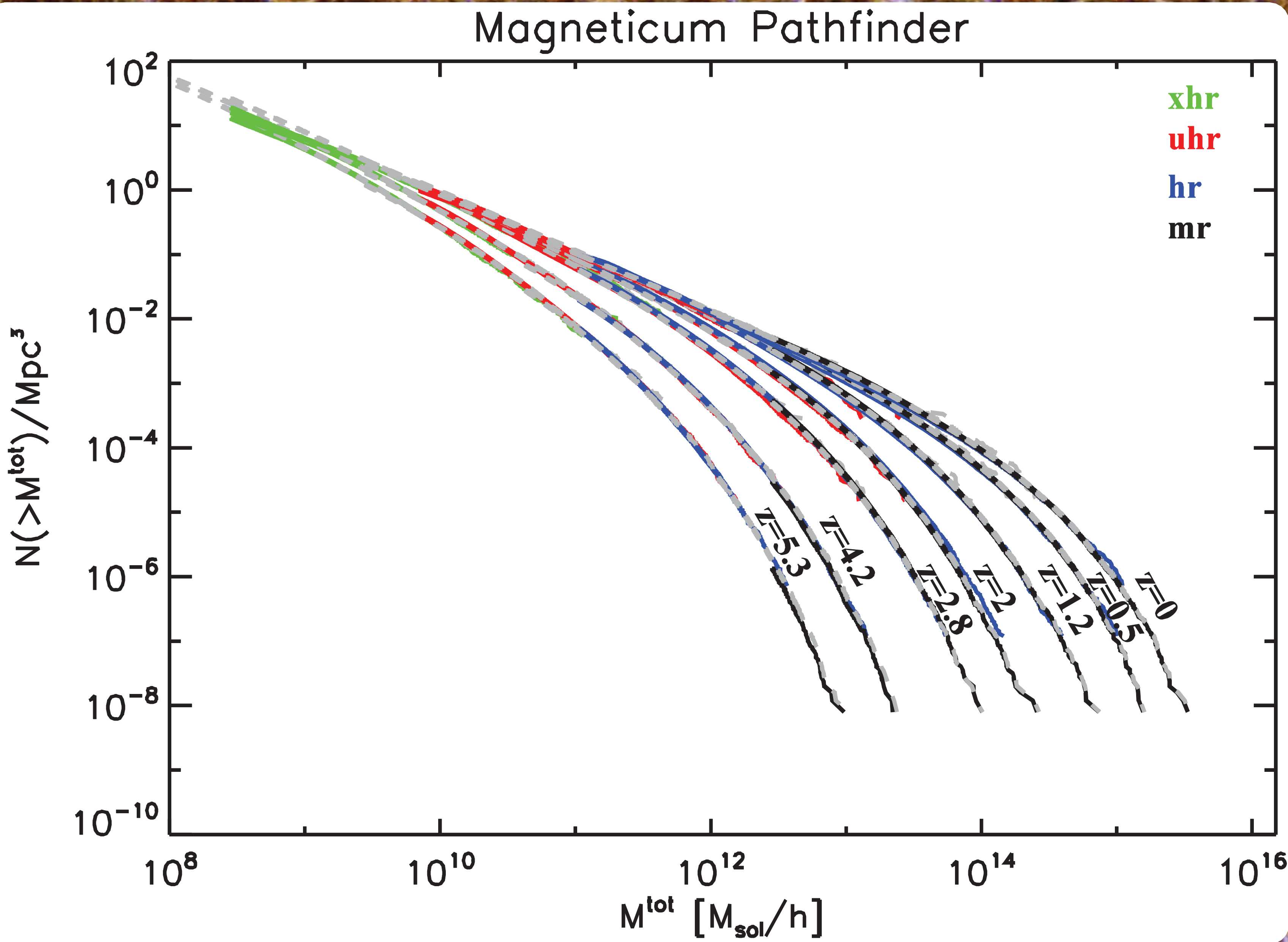




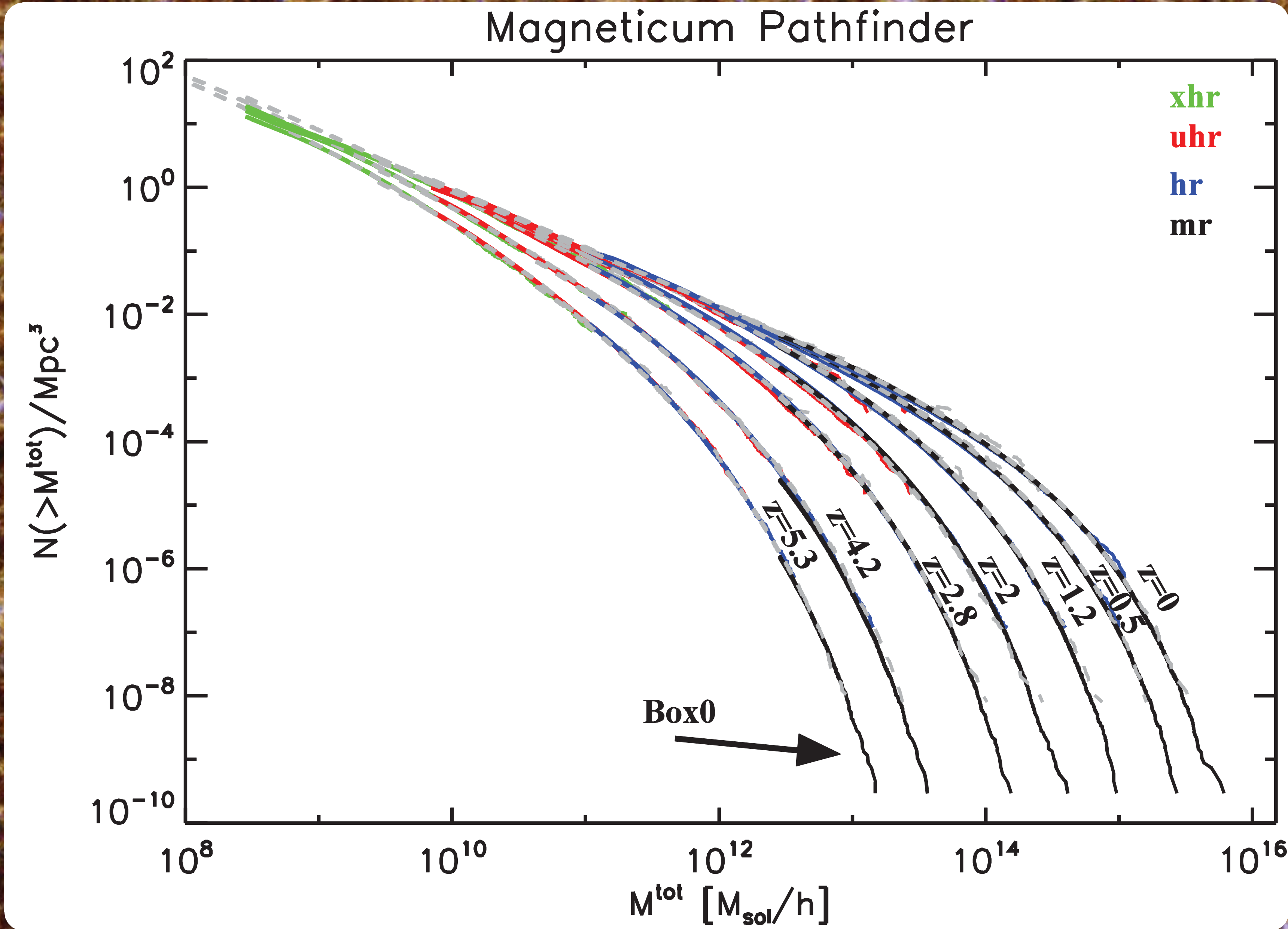


Bocquet et al. 2015

Verifying with Magneticum

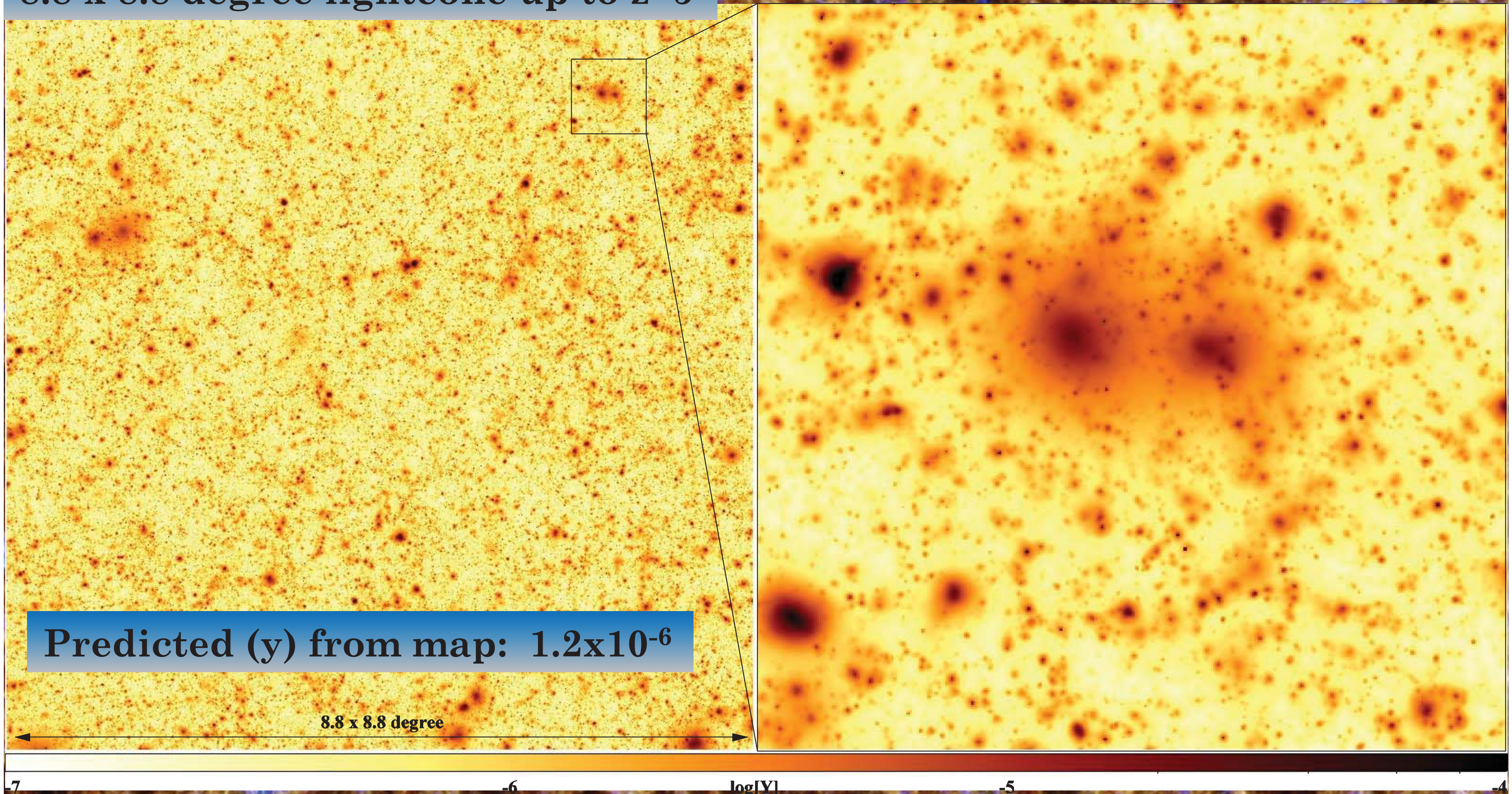


Verifying with Magneticum



Magneticum Pathfinder SZ Maps

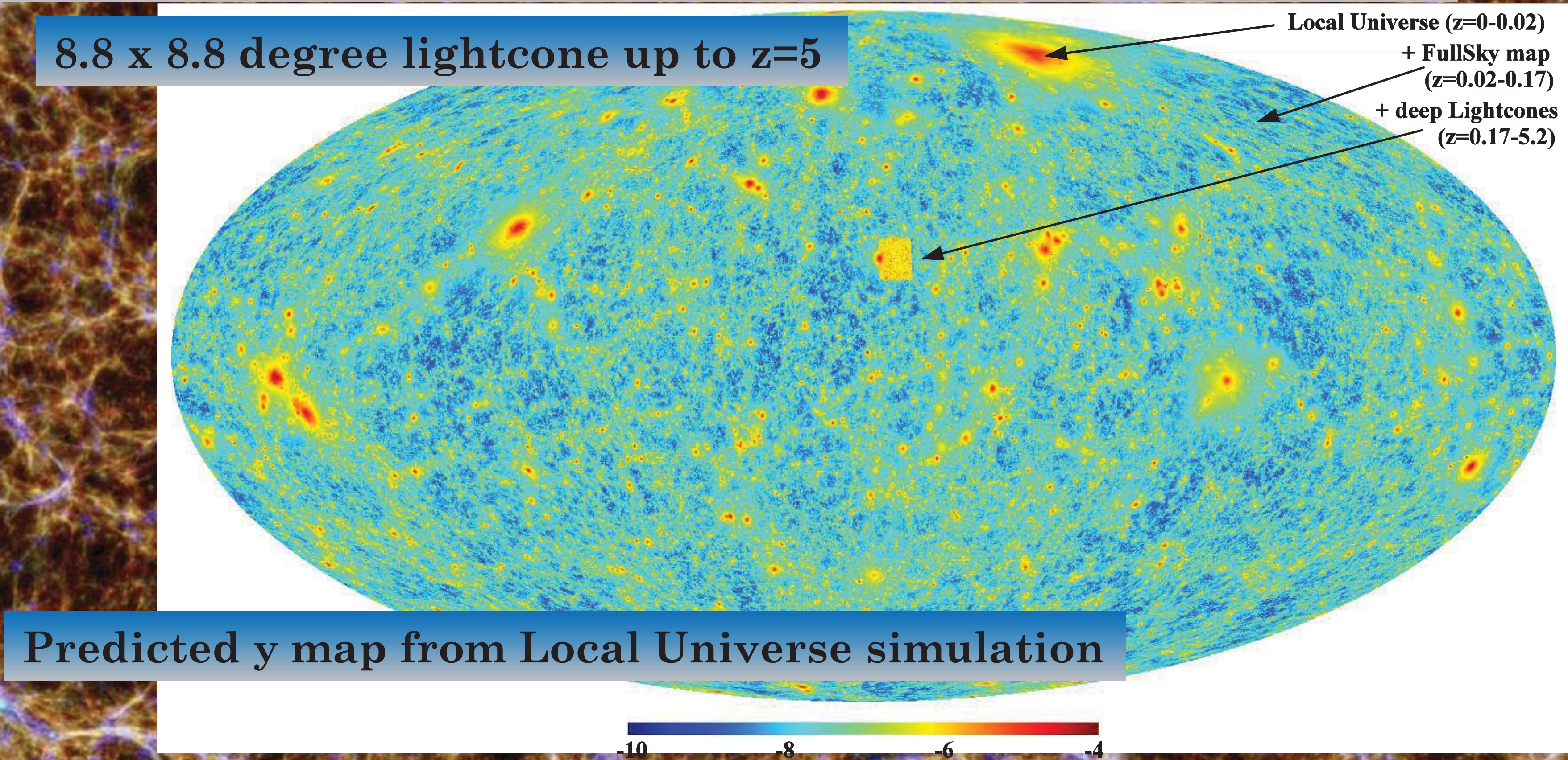
8.8 x 8.8 degree lightcone up to z=5

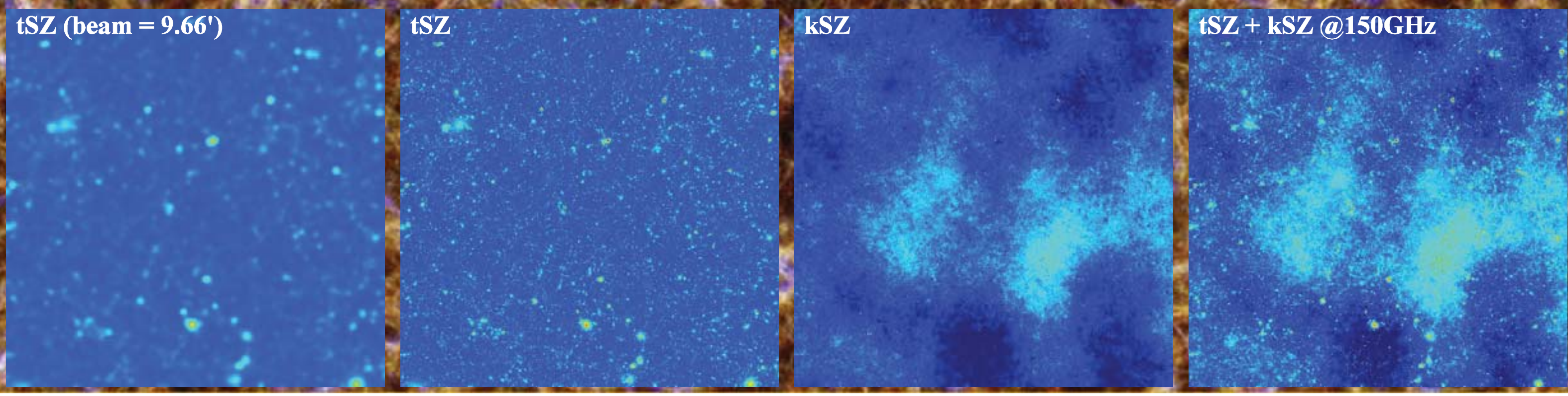


Predicted ⟨y⟩ from map: $1.2\text{x}10^{-6}$

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

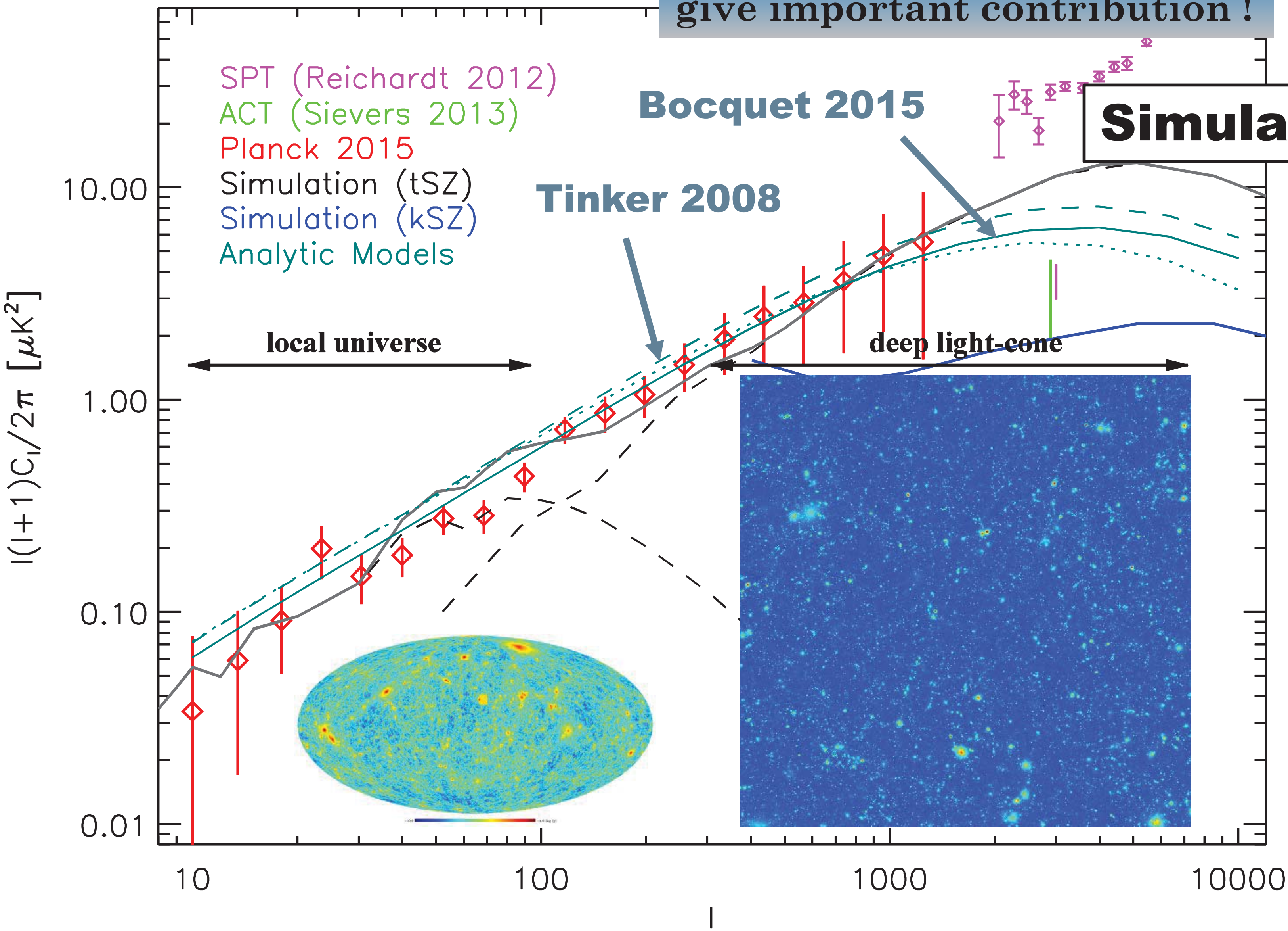
Magneticum Pathfinder SZ Maps



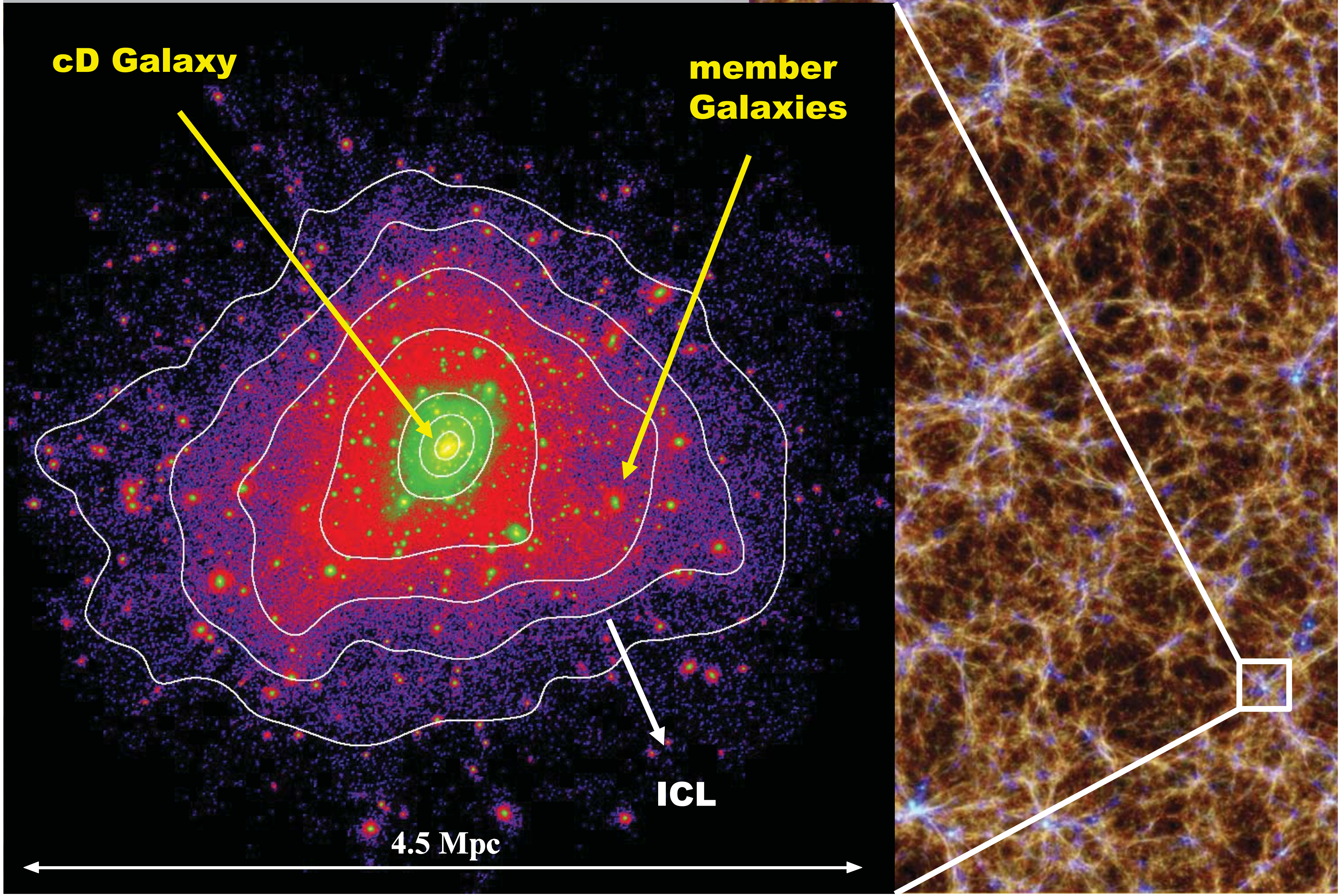


SZ power spektrum

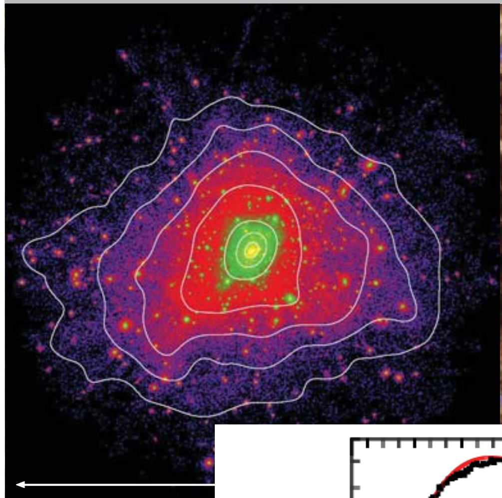
Local Universe simulations give important contribution !



Intra cluster light

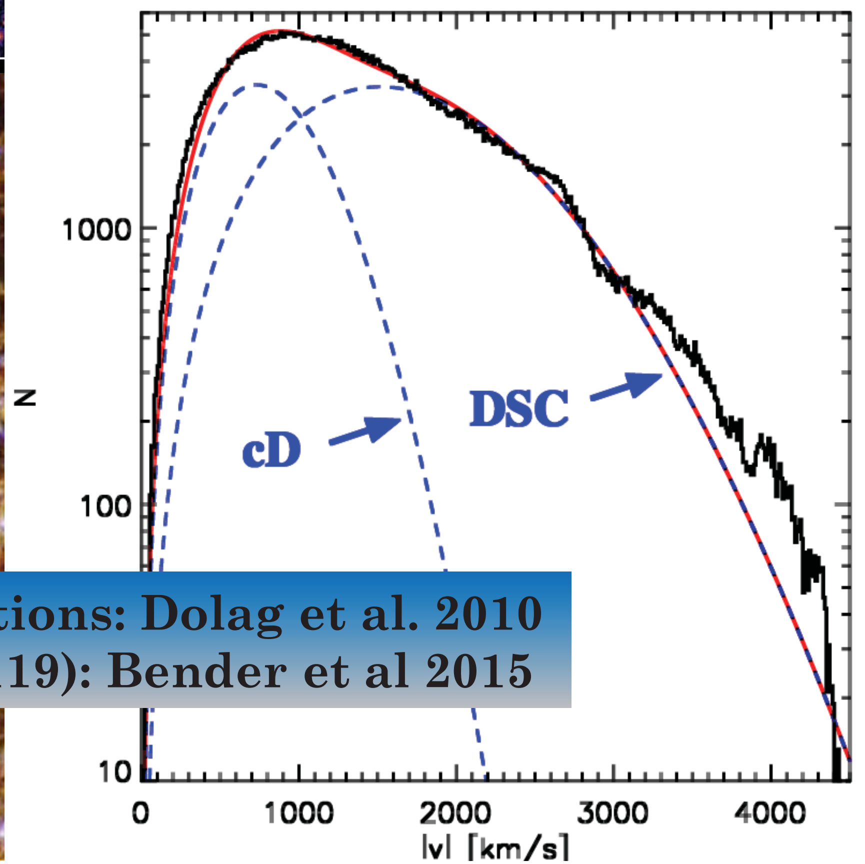


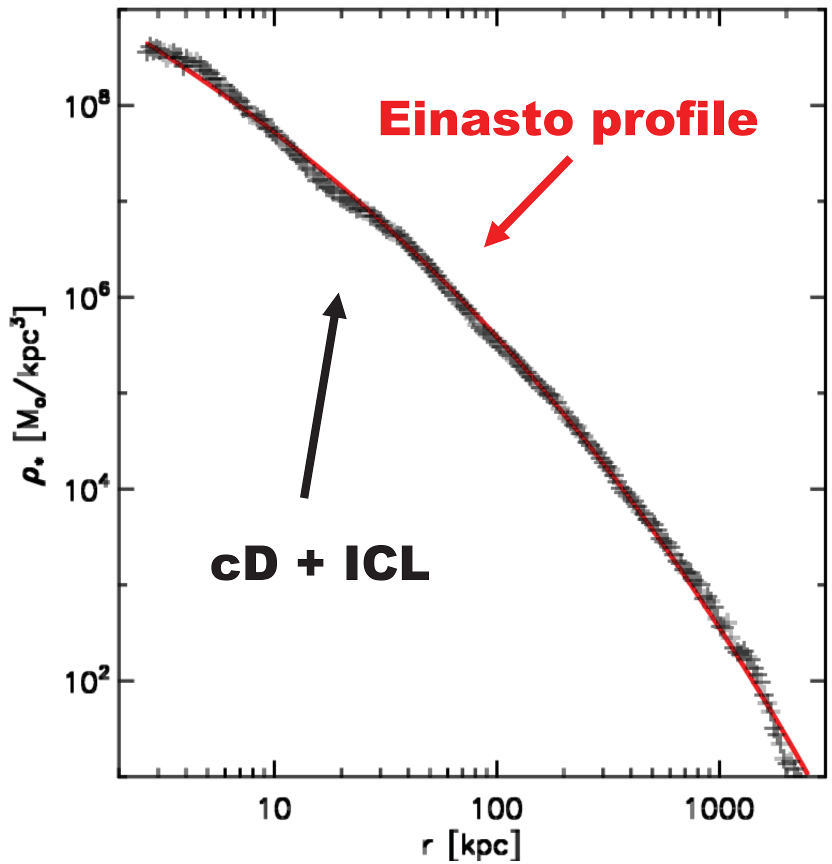
Intra cluster light



Einasto profile

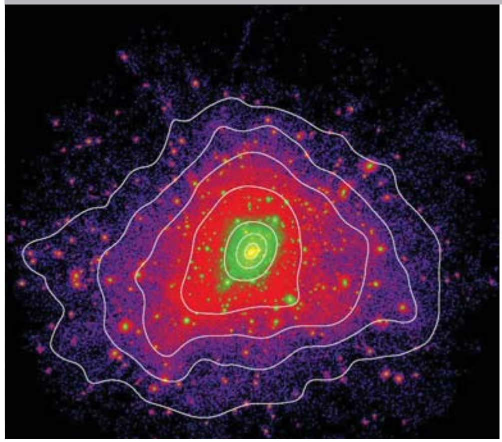
$$\rho_{-2}\exp\left\{-\frac{2}{\alpha_{Ein}}\left[\left(\frac{r}{r_{-2}}\right)^{\alpha_{Ein}}-1\right]\right\}$$

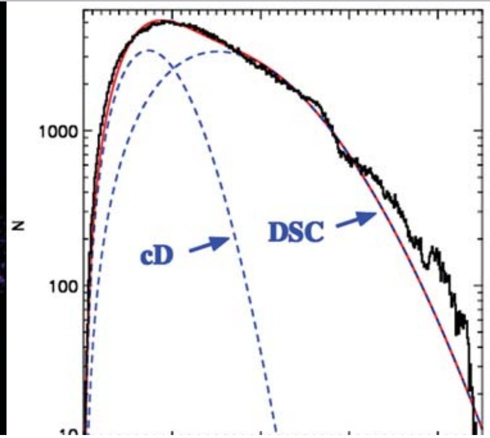


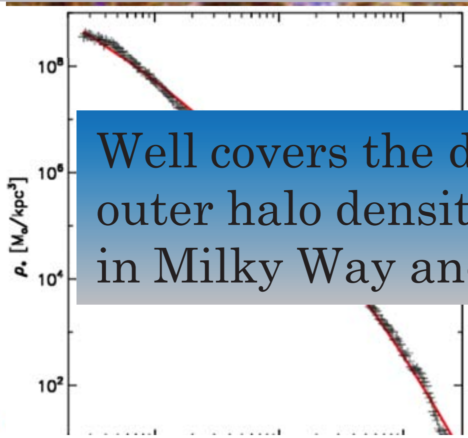


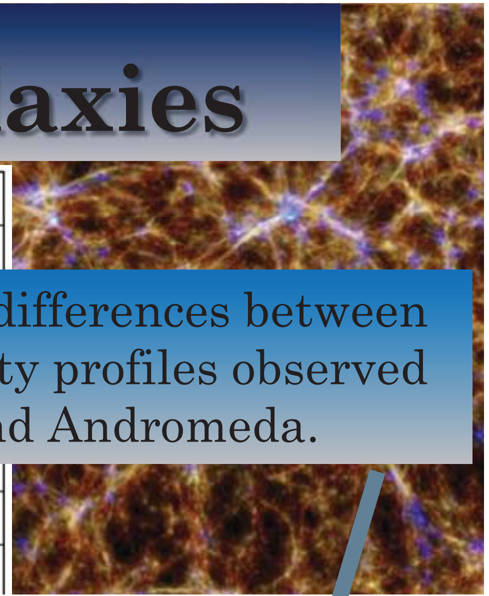
Simulations: Dolag et al. 2010
Obs (A119): Bender et al 2015

From ICL to outer halos of galaxies

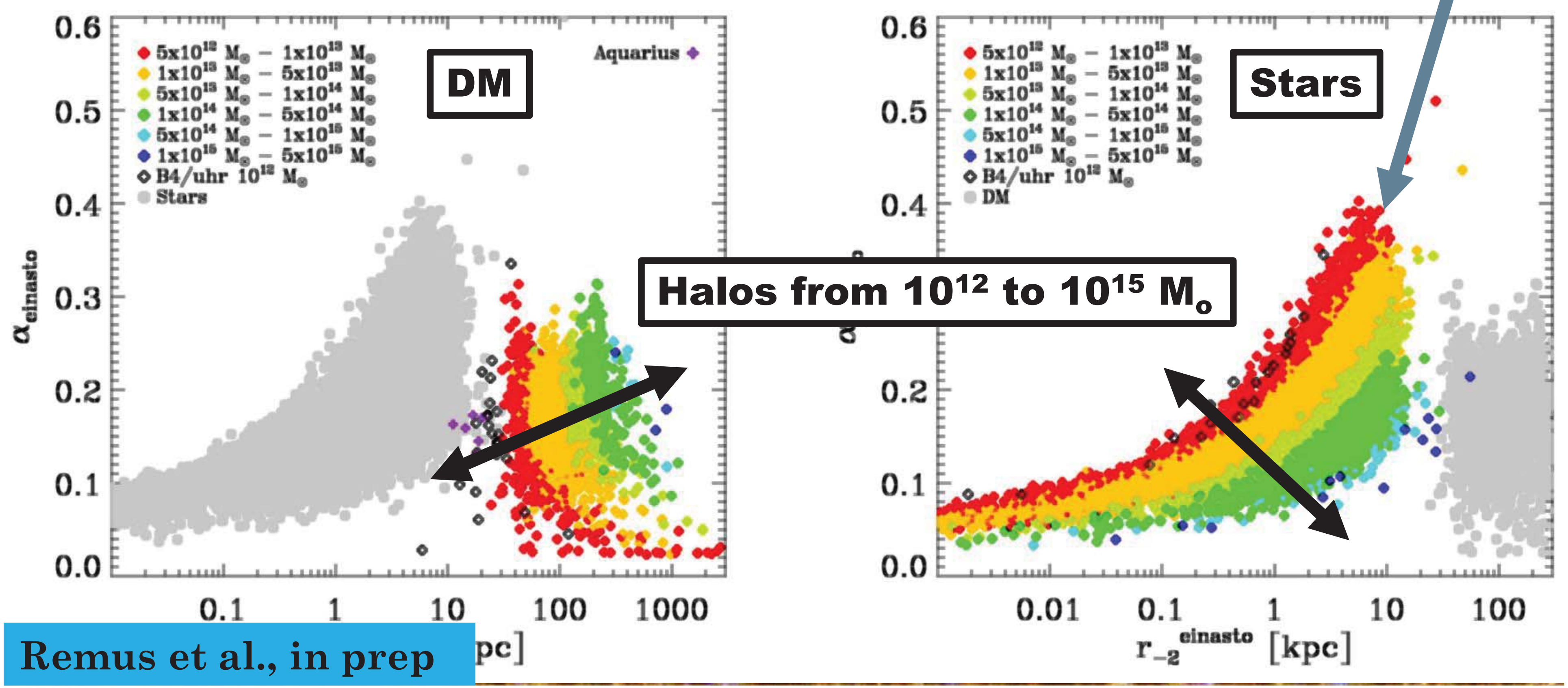






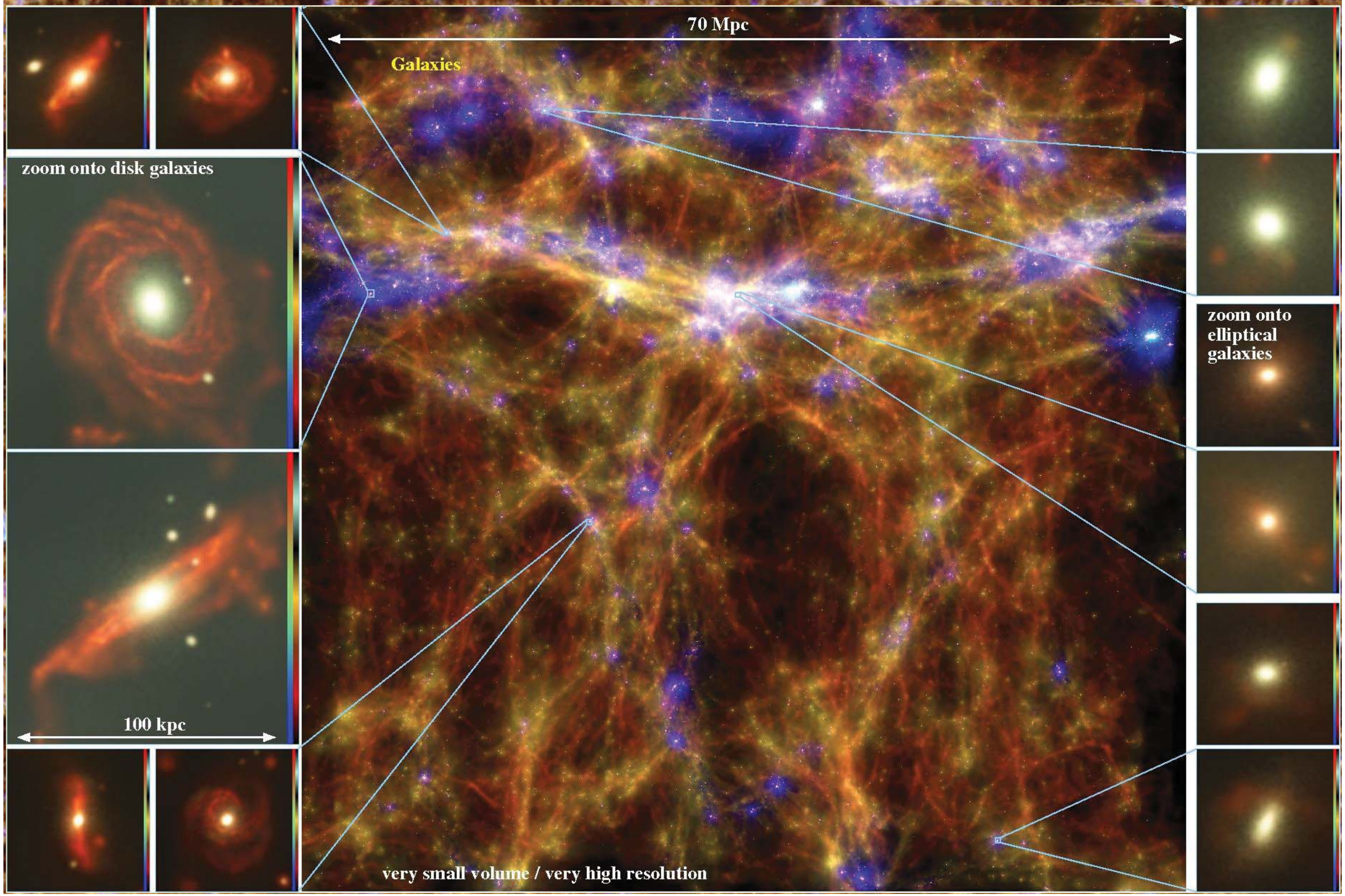


Well covers the differences between outer halo density profiles observed in Milky Way and Andromeda.

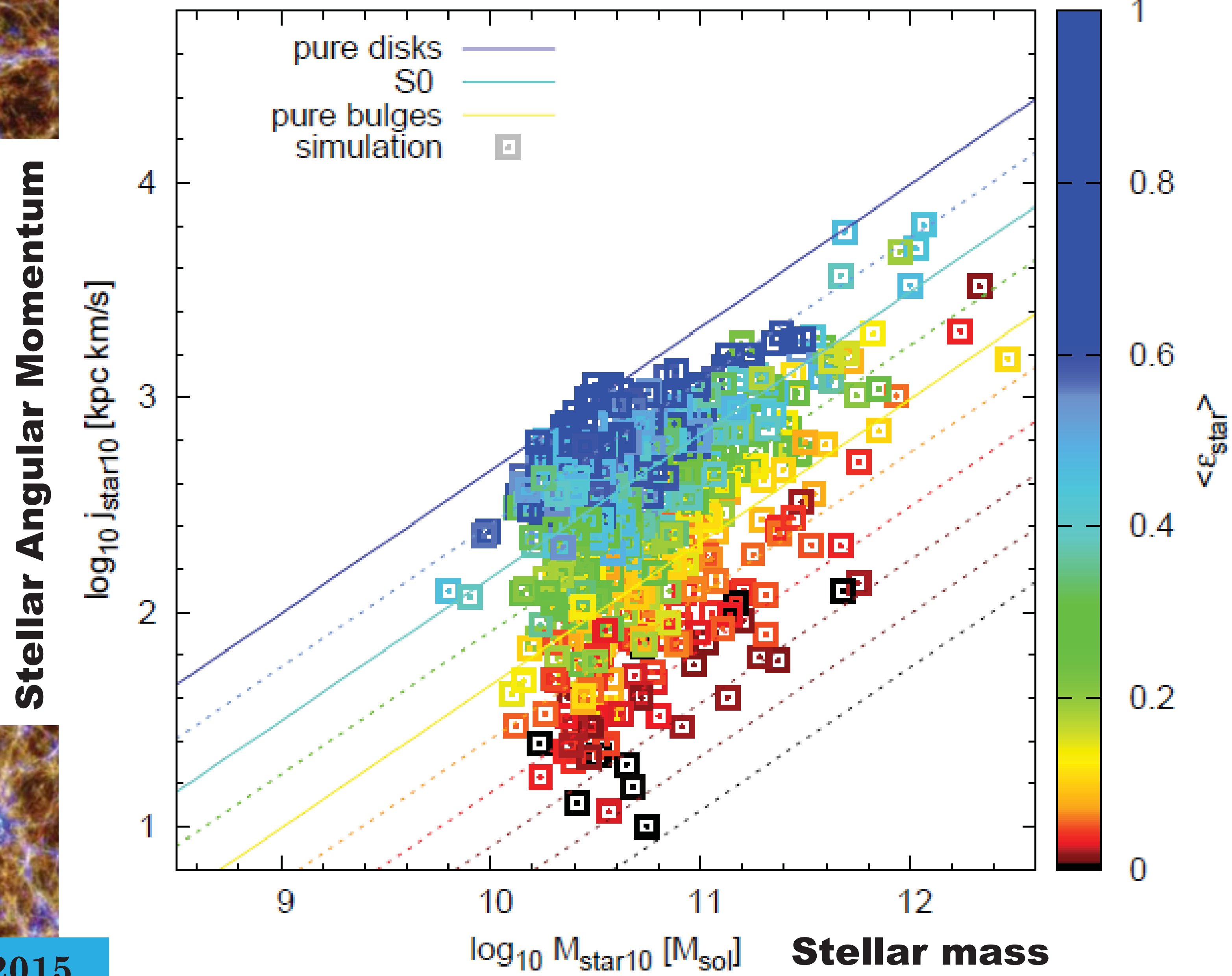


Remus et al., in prep

Morphology of galaxies

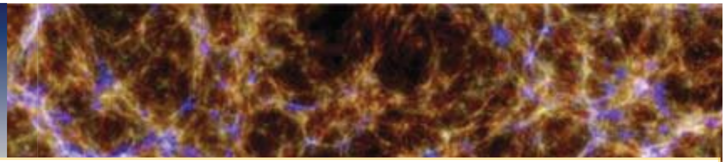


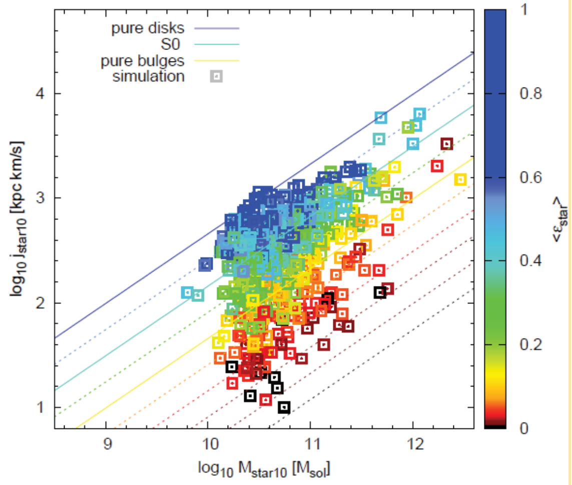
Dynamics of galaxies

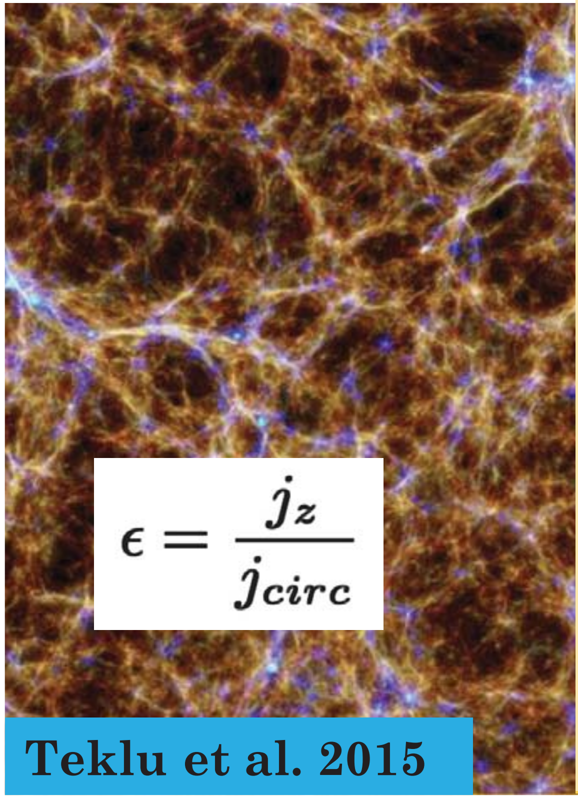


Teklu et al. 2015

Dynamics of galaxies

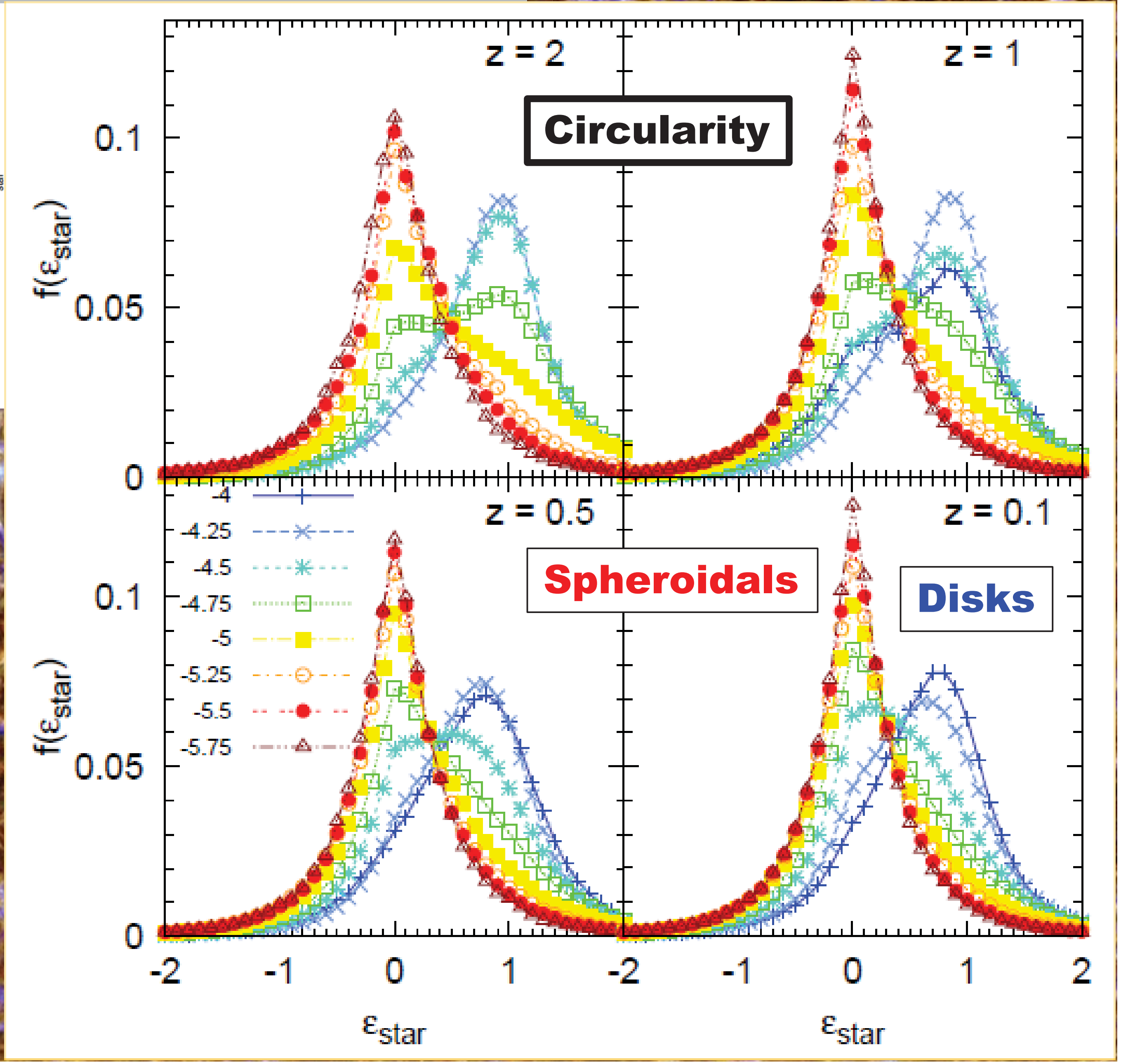




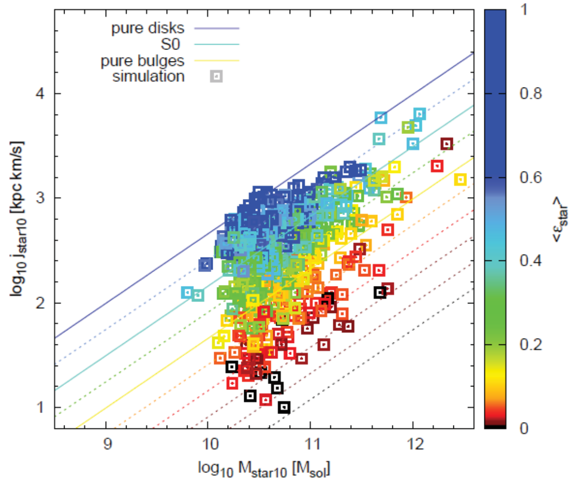


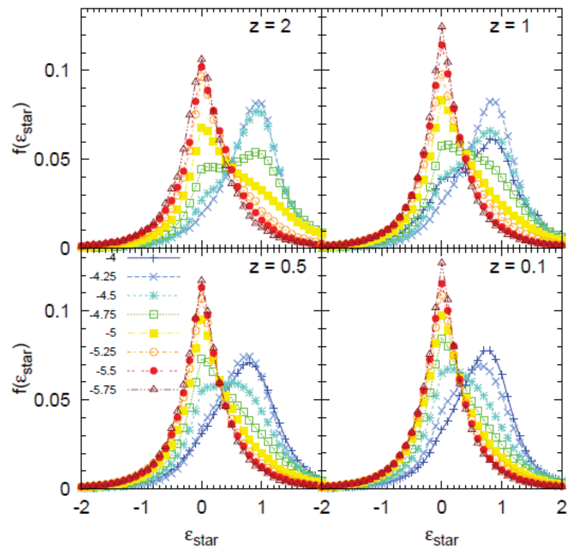
$$\epsilon = \frac{j_z}{j_{circ}}$$

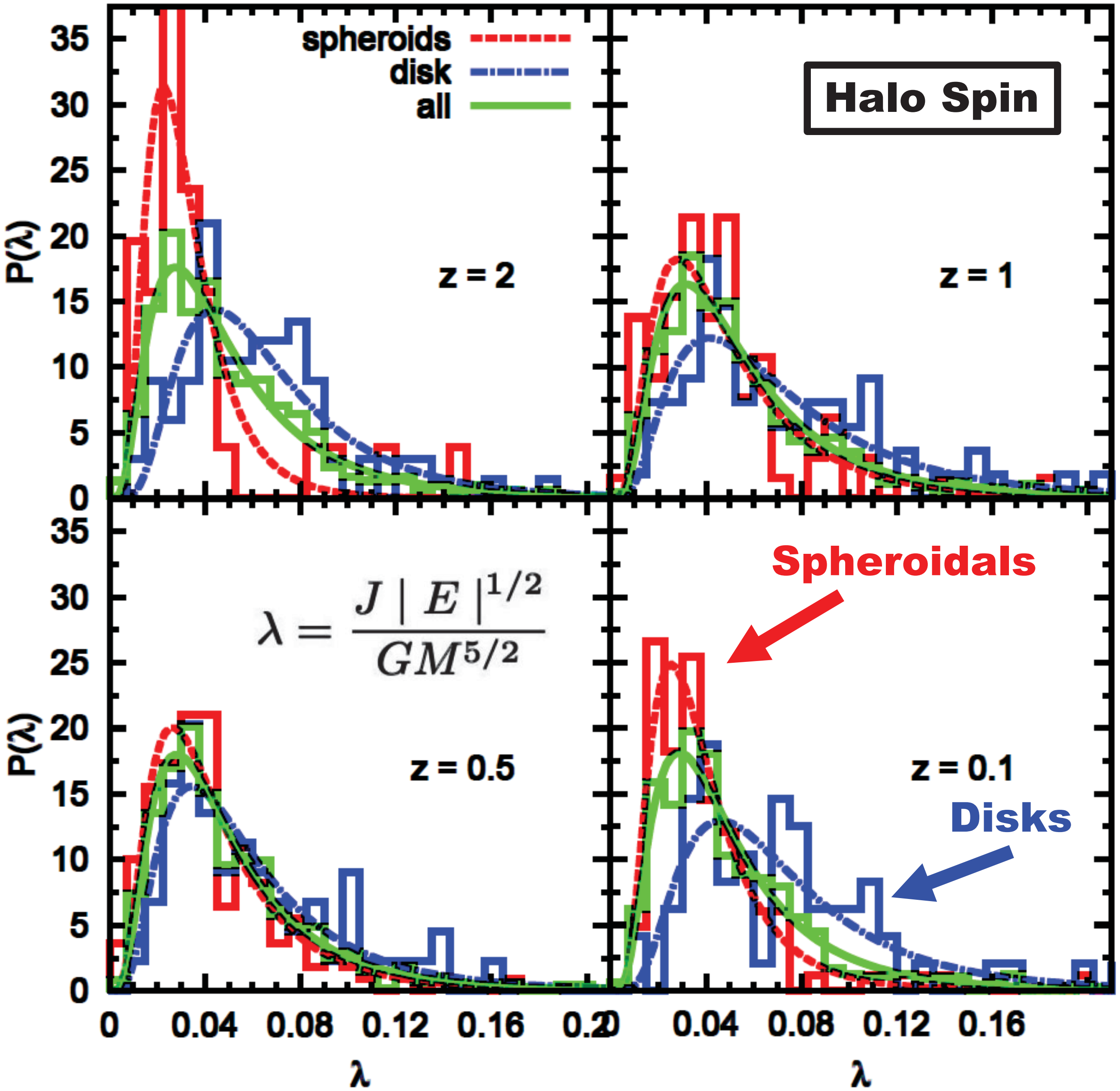
Teklu et al. 2015



Dynamics of galaxies



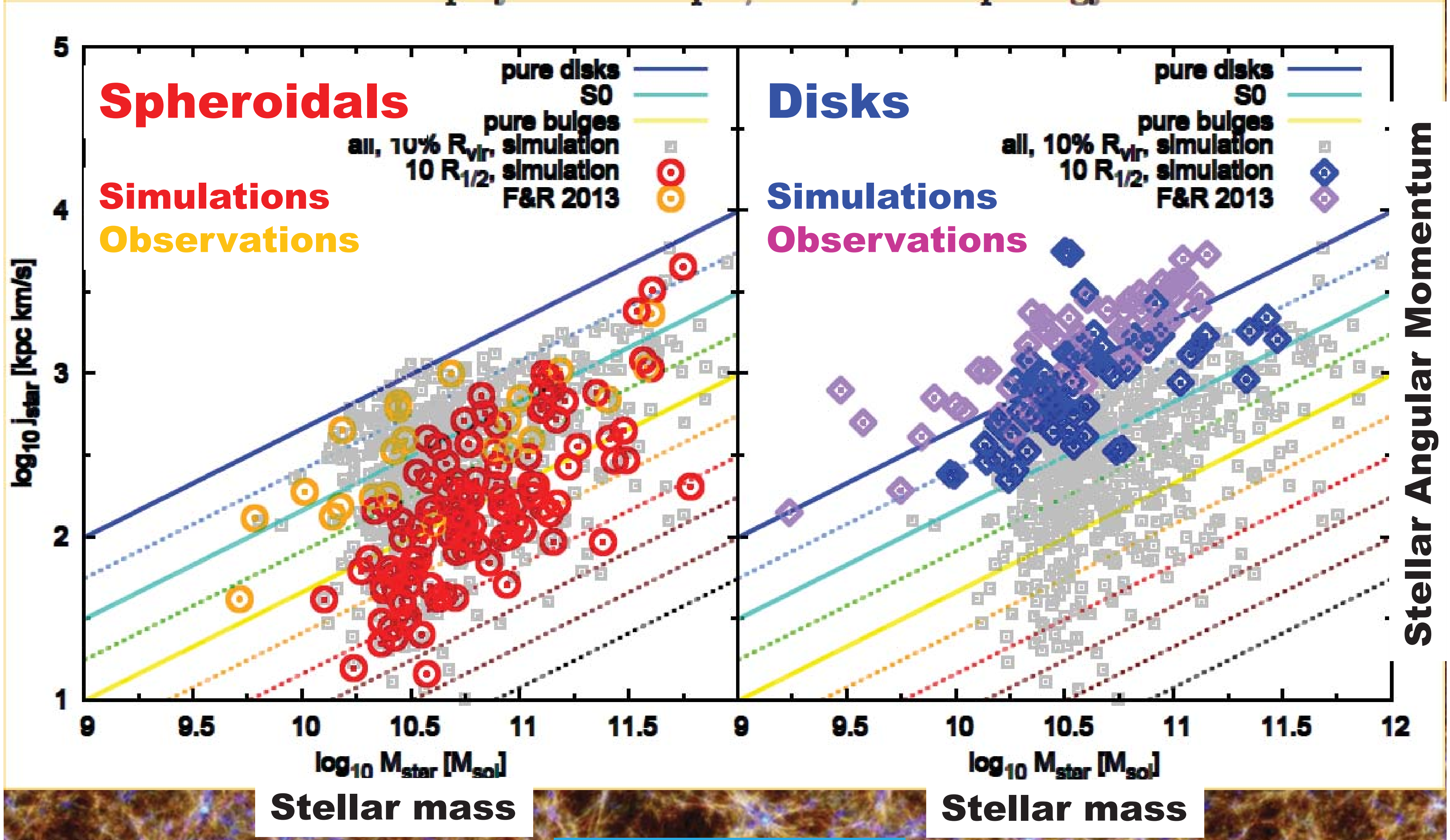




Holds even for the DM only simulation !

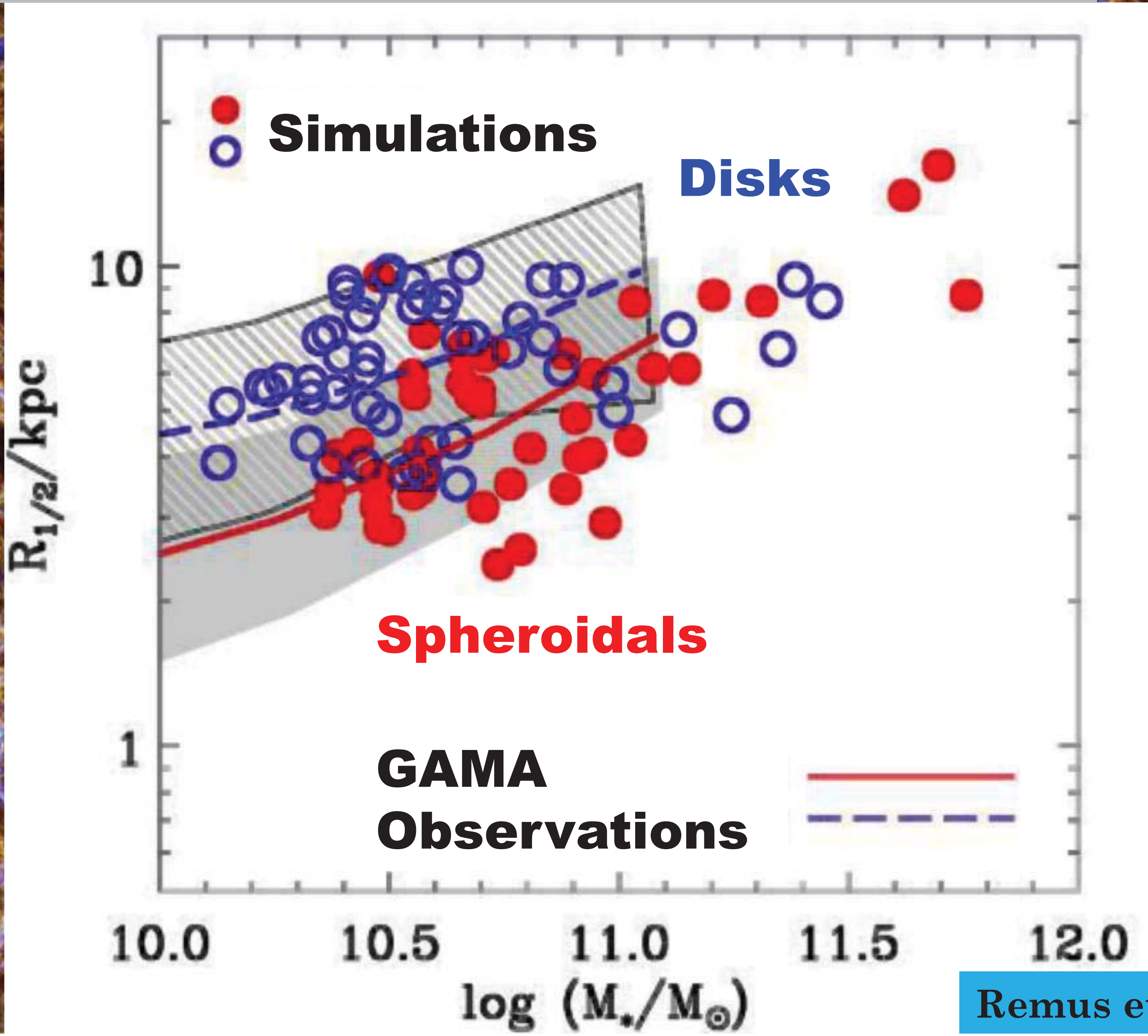
Teklu et al. 2015

Simulations vs. observations



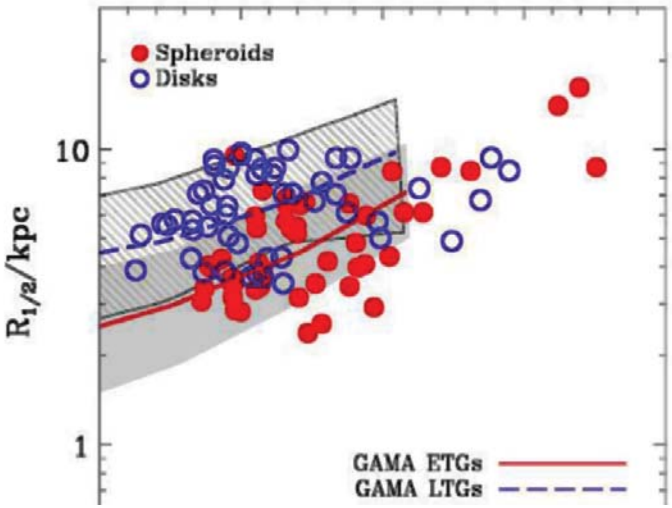
Teklu et al. 2015

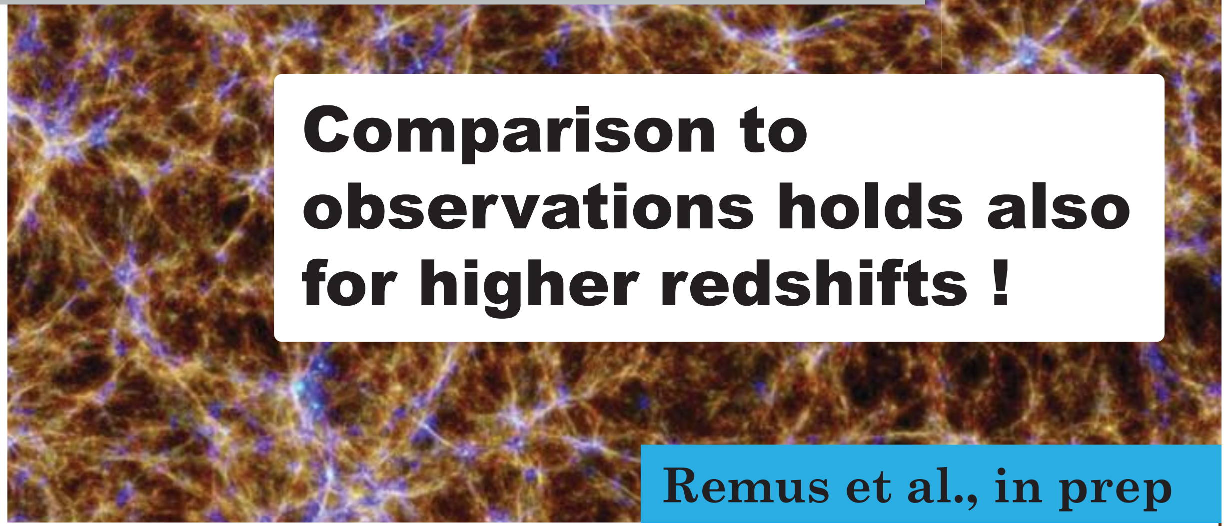
Simulations vs. observations



Remus et al. 2015

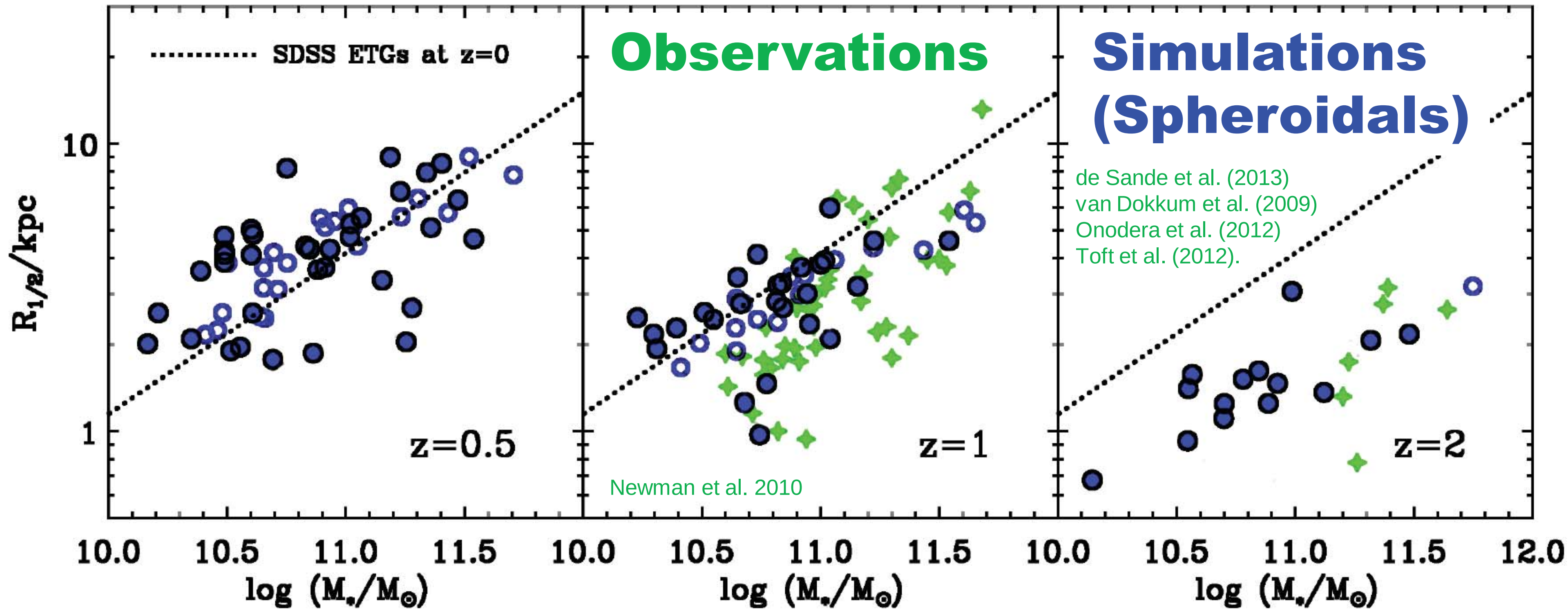
Simulations vs. observations



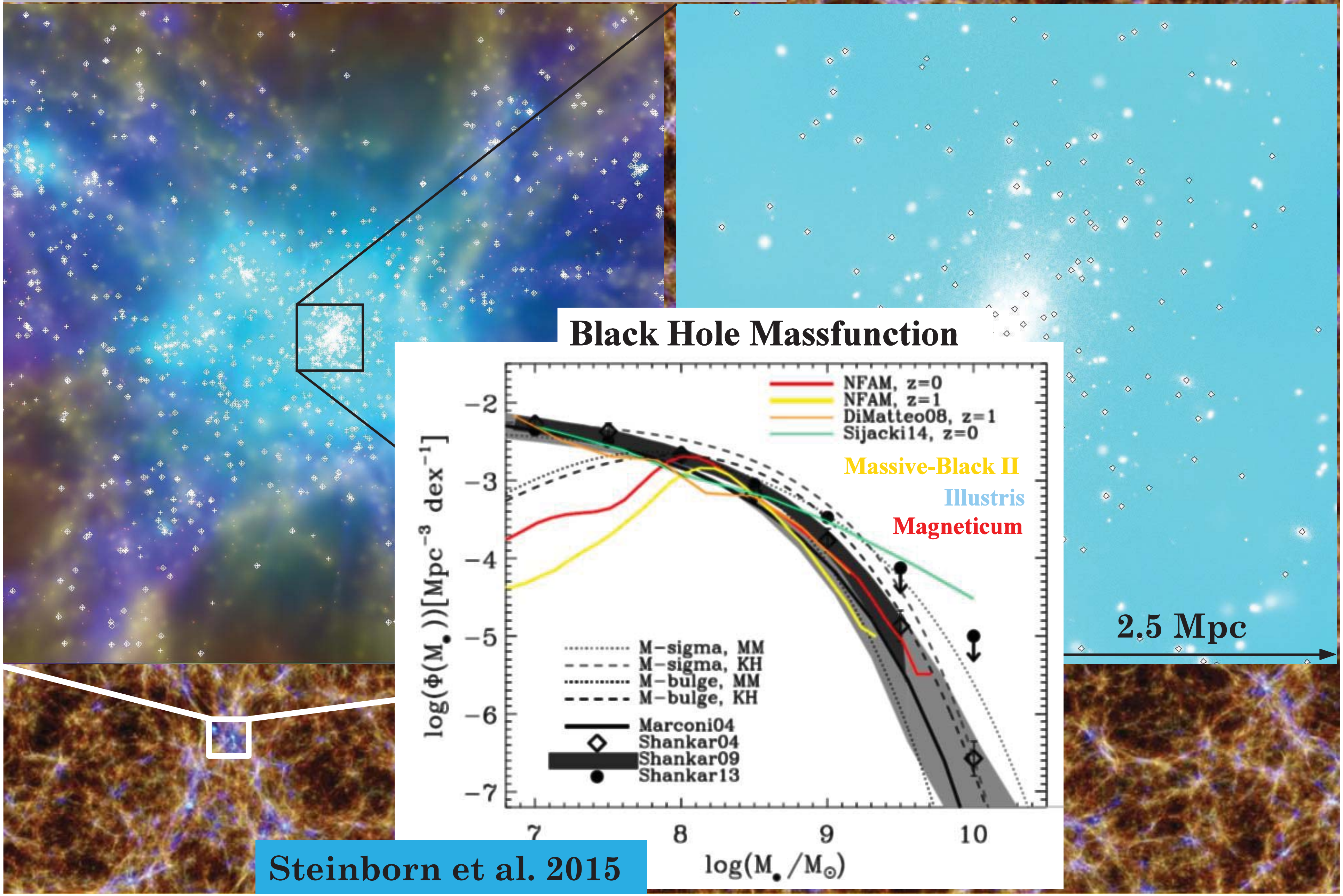


Comparison to observations holds also for higher redshifts !

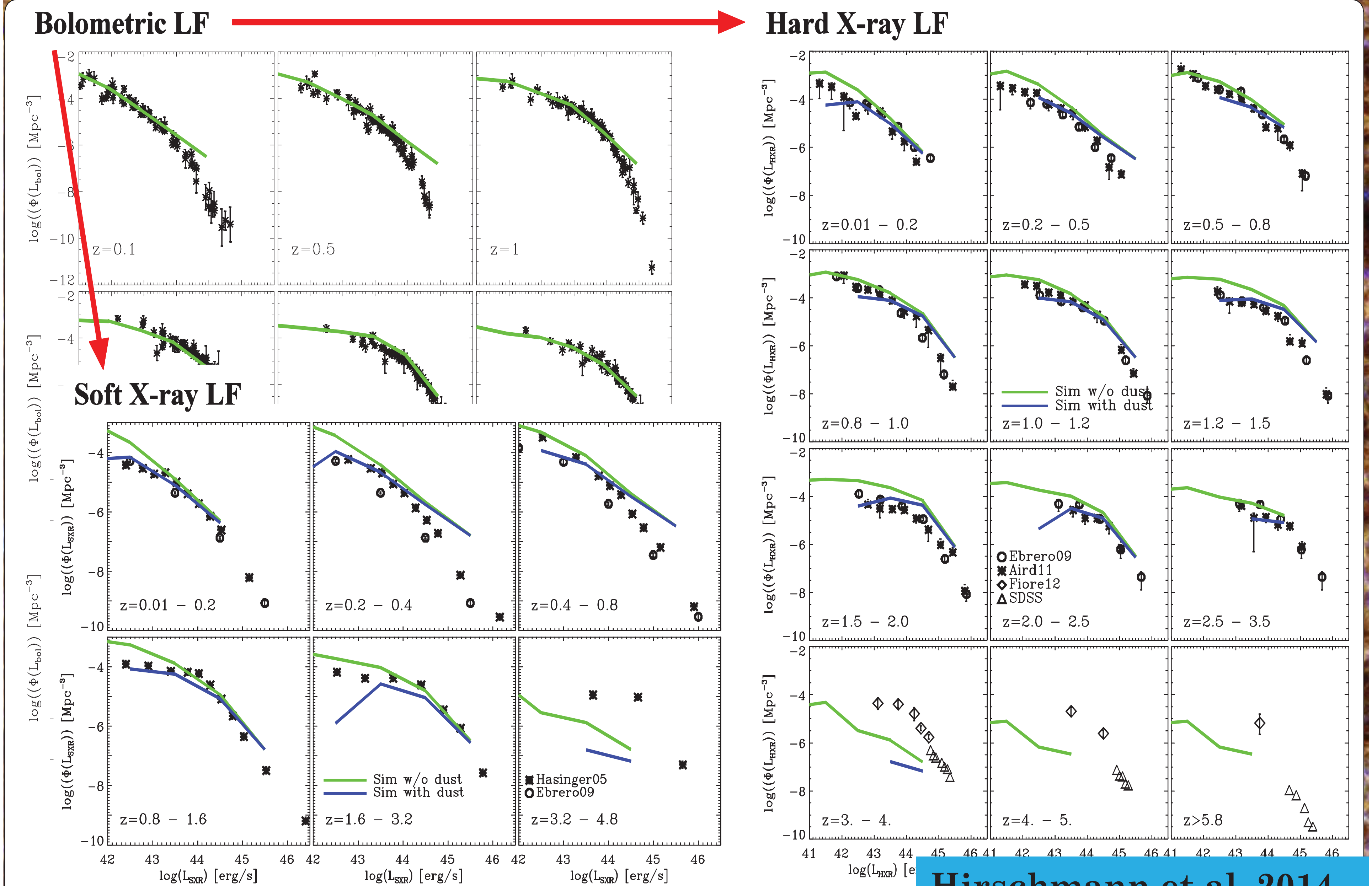
Remus et al., in prep



Black Hole properties

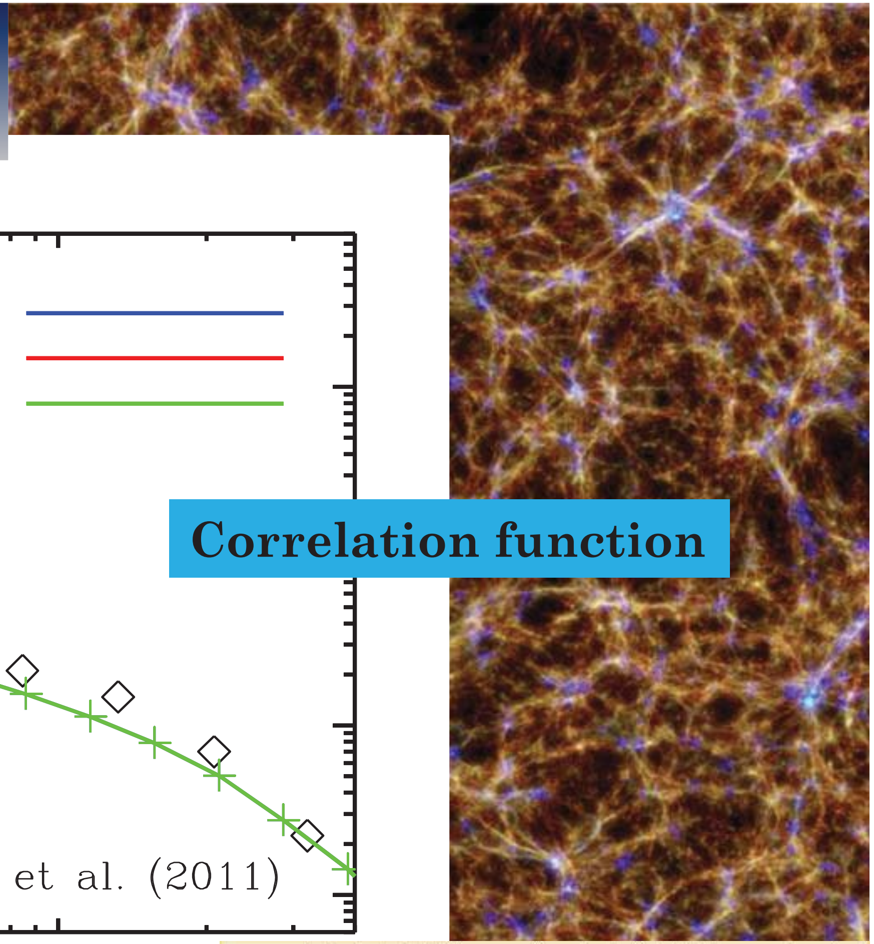


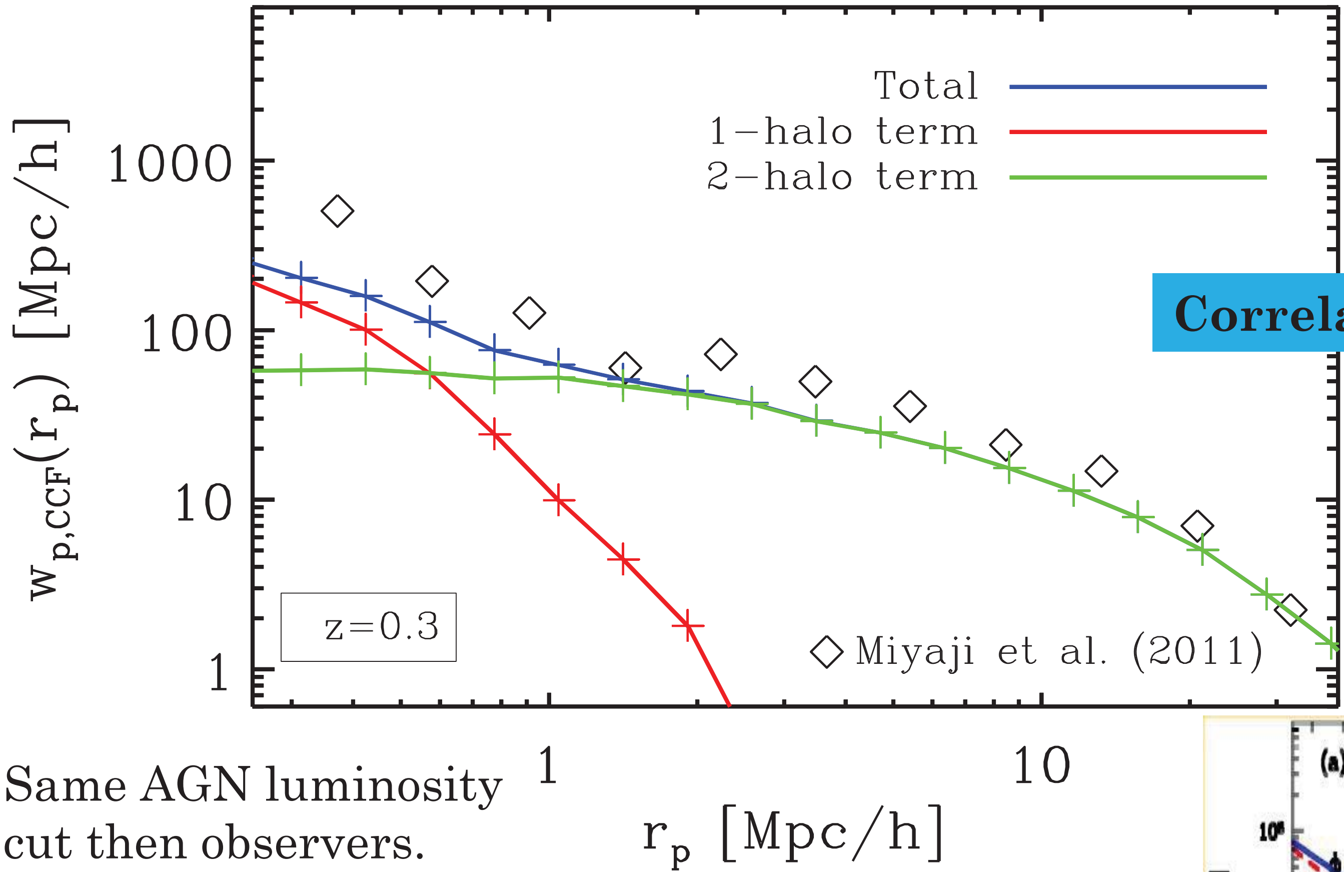
AGN properties (optical + X-ray)



Hirschmann et al. 2014

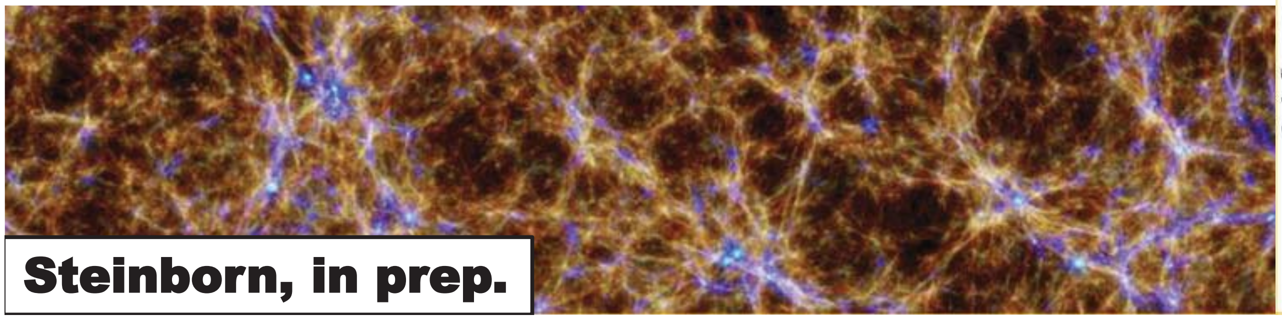
AGN distribution

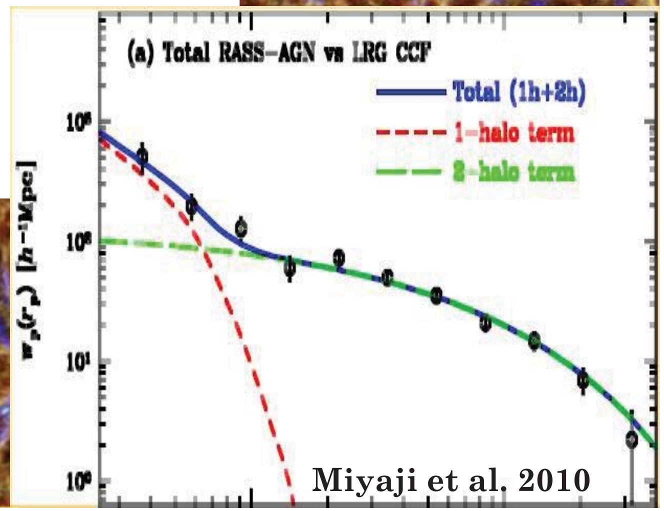




Correlation function

Same AGN luminosity cut then observers.





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 constarain sub-grid models

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