The Young and the Wild:
What happens to Protoclusters forming at z≈4?

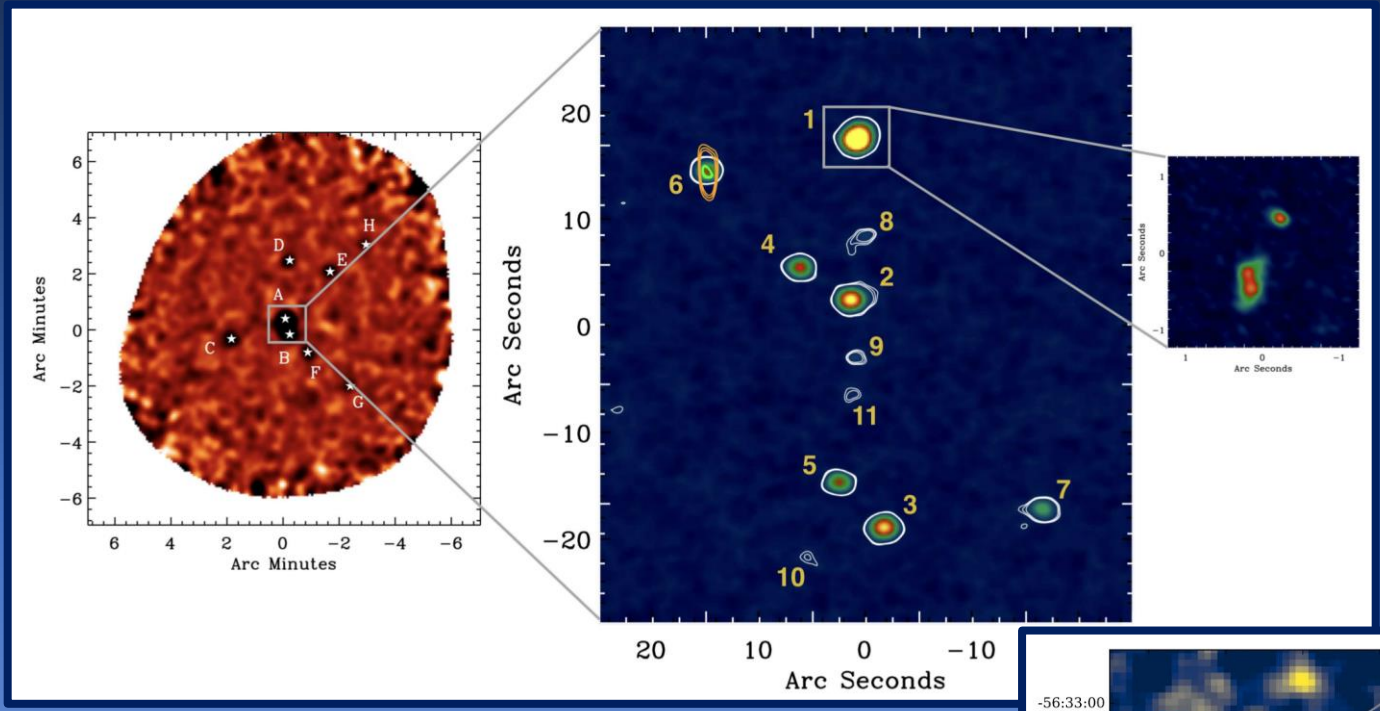
Rhea-Silvia Remus

with Klaus Dolag, Felix Schulze, Elena Hernandez

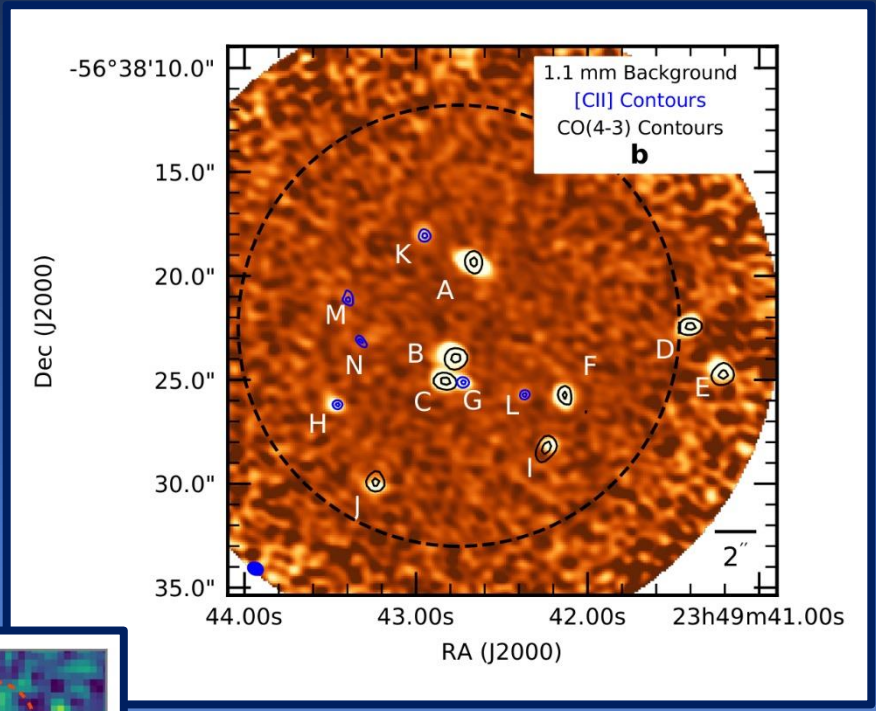
and Scott C. Chapman, Helmut Dannerbauer

Protoclusters: Galaxies in Confinement, 03.09.2020

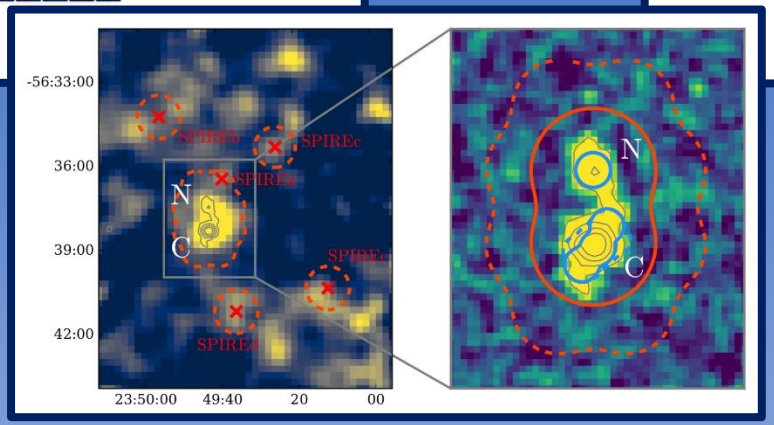
Protoclusters @ z≈4.0



Estimated $M_{tot} = 4.4 \times 10^{13}\ M_{\odot}$
Oteo et al., 2018

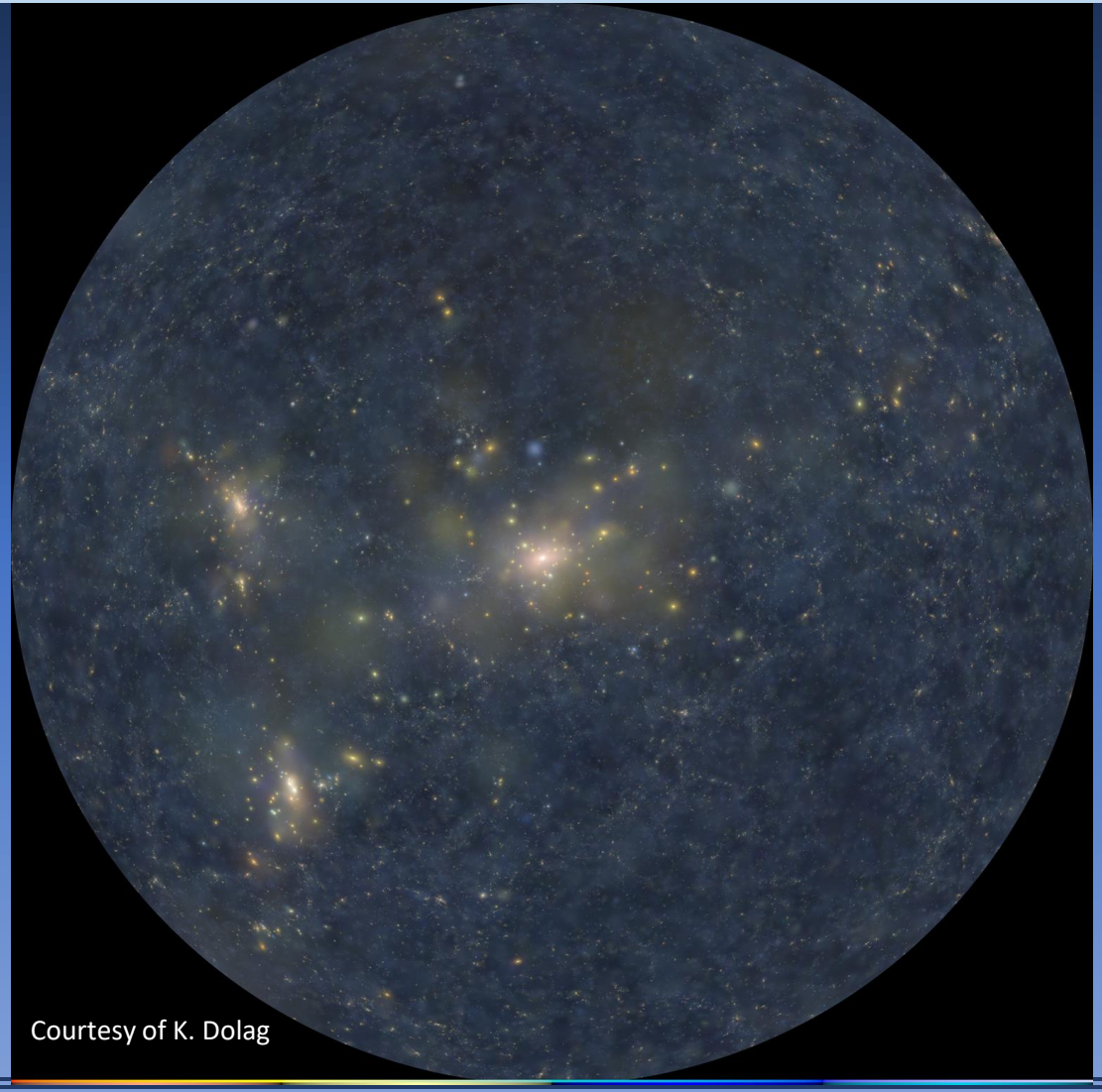


Estimated $M_{tot} = 1.16 \times 10^{13}\ M_{\odot}$
Miller et al., 2018



Estimated $M_{tot} = 9 \pm 5\ \times 10^{12}\ M_{\odot}$
Hill et al., 2020

The Simulations: Magneticum



www.magneticum.org

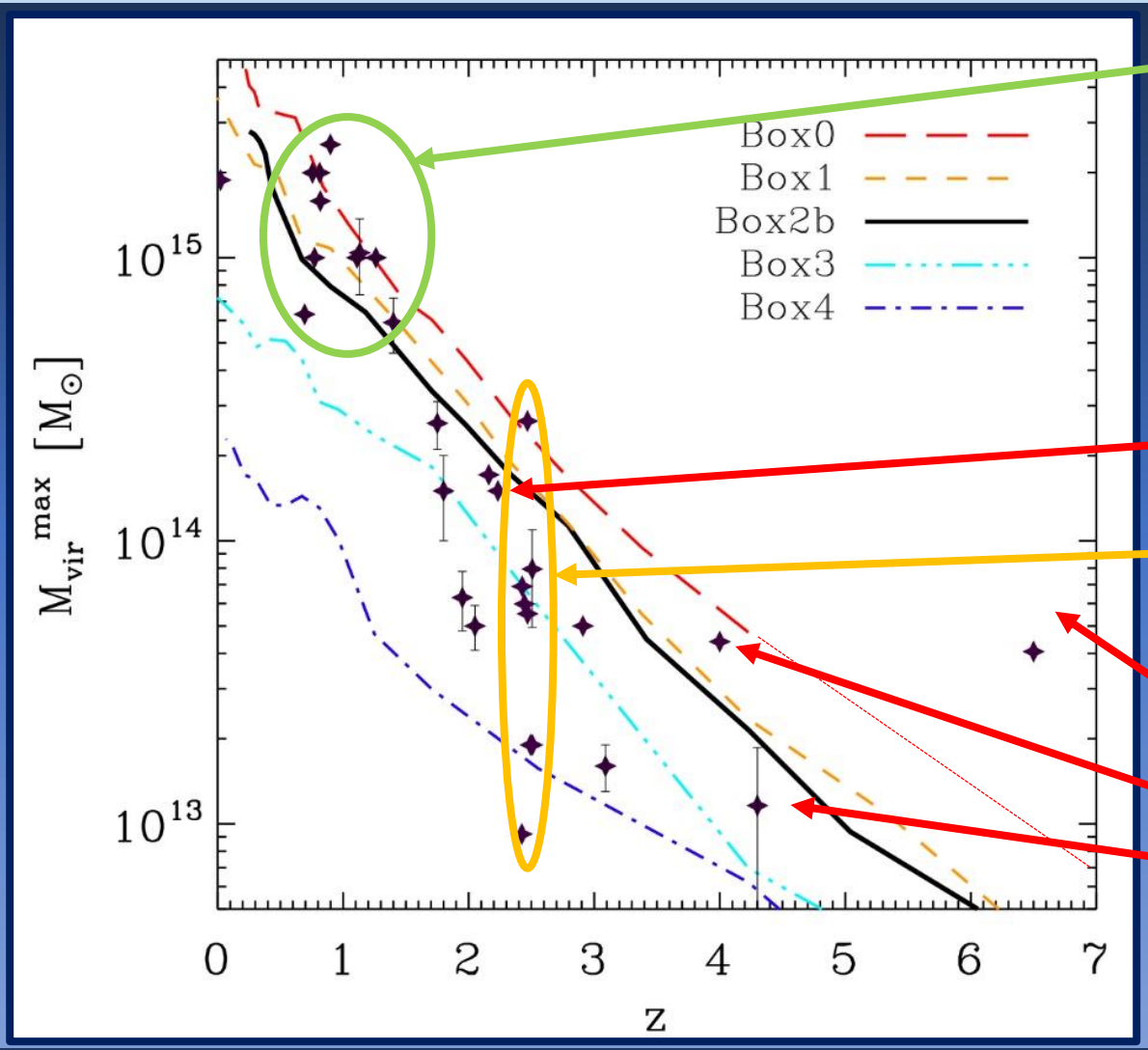
Box	Mpc/h	mr	hr	uhr
0	2688	y		
1	896	y		
2b	640	y	y	
3	128	y	y	(z=2)
4	48	y	y	y

	mr	hr	uhr
$m_{DM}\ (M_\odot/h)$	$1.3 \cdot 10^{10}$	$6.9 \cdot 10^{8}$	$3.7 \cdot 10^{7}$
$m_{Gas}\ (M_\odot/h)$	$2.6 \cdot 10^{9}$	$1.4 \cdot 10^{7}$	$7.3 \cdot 10^{6}$

One gas particle can spawn up to 4 stellar particles.

- Modified SPH version of GADGET-3 (incl. thermal conduction)
- Feedback from stellar winds
- Feedback from AGN
- Metal enrichment and star formation follow pattern of metal production from SNIa, SNII & AGB
- Gas cooling depends on local metallicity

Simulations: Overview



ORELSE
(Tomczak et al., 2017)

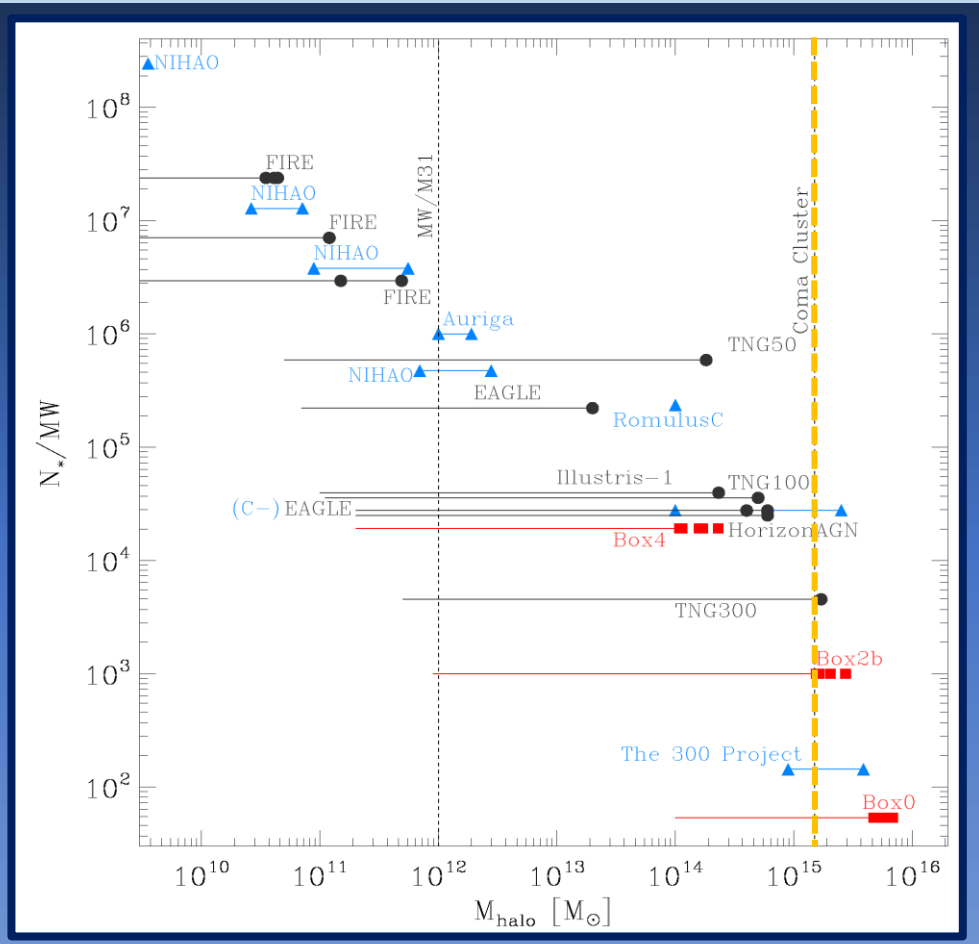
Darvish et al., 2020

Hyperion
(Cucciati et al., 2018)

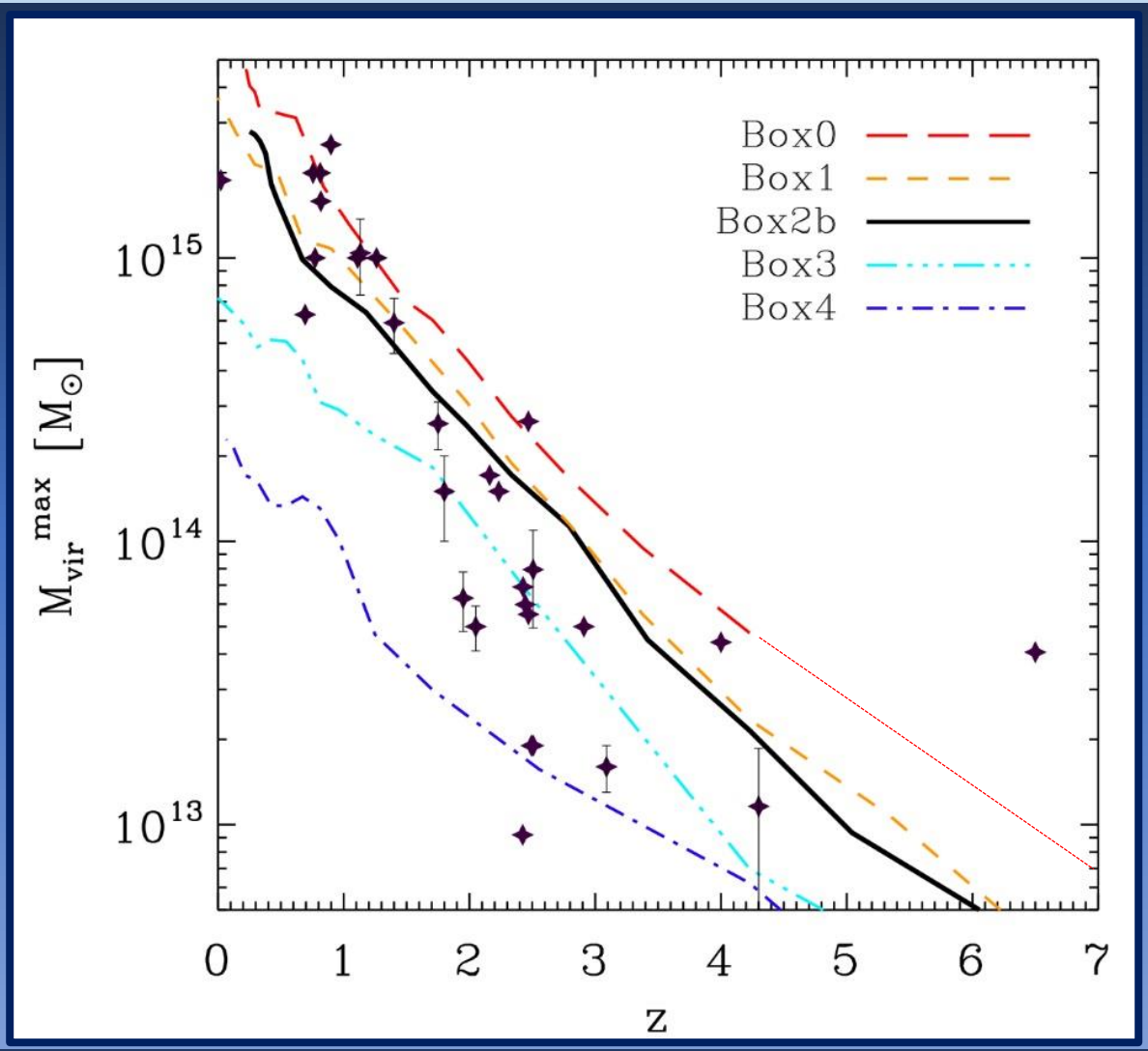
Chanchaiworawit et al.,2019

Oteo et al., 2018

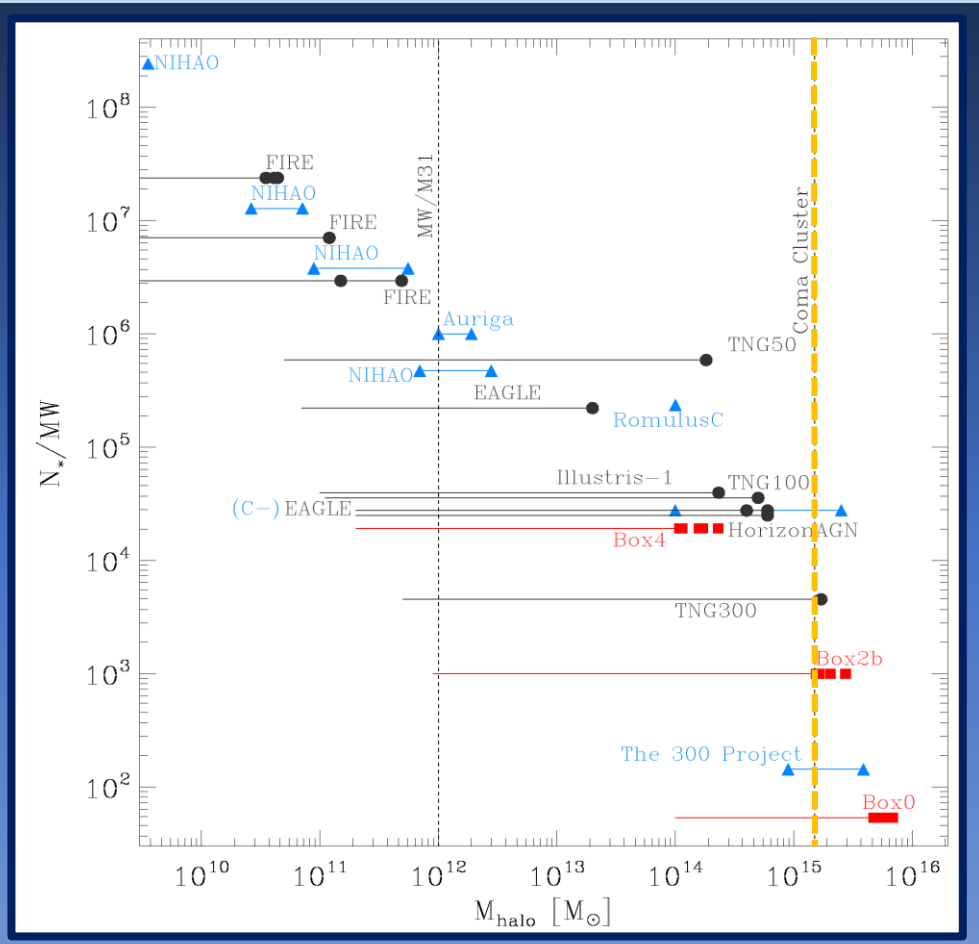
Miller et al., 2018



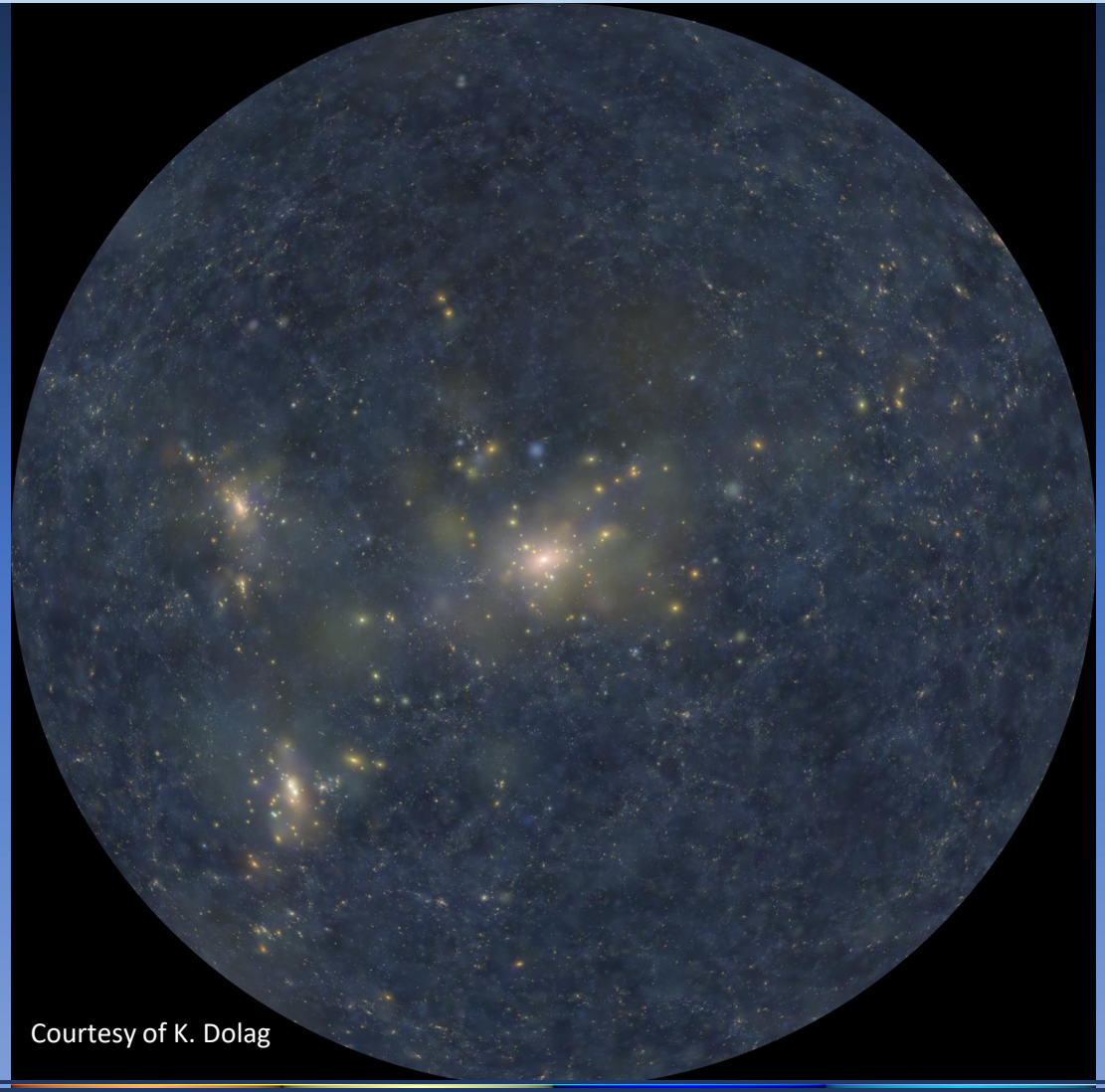
Simulations: Overview



Box	Mpc/h
0	2688
1	896
2b	640
3	128
4	48



The Simulations: Magneticum


Courtesy of K. Dolag

www.magneticum.org

Box	Mpc/h	mr	hr	uhr
0	2688	y		
1	896	y		
2b	640	y	y	
3	128	y	y	(z=2)
4	48	y	y	y

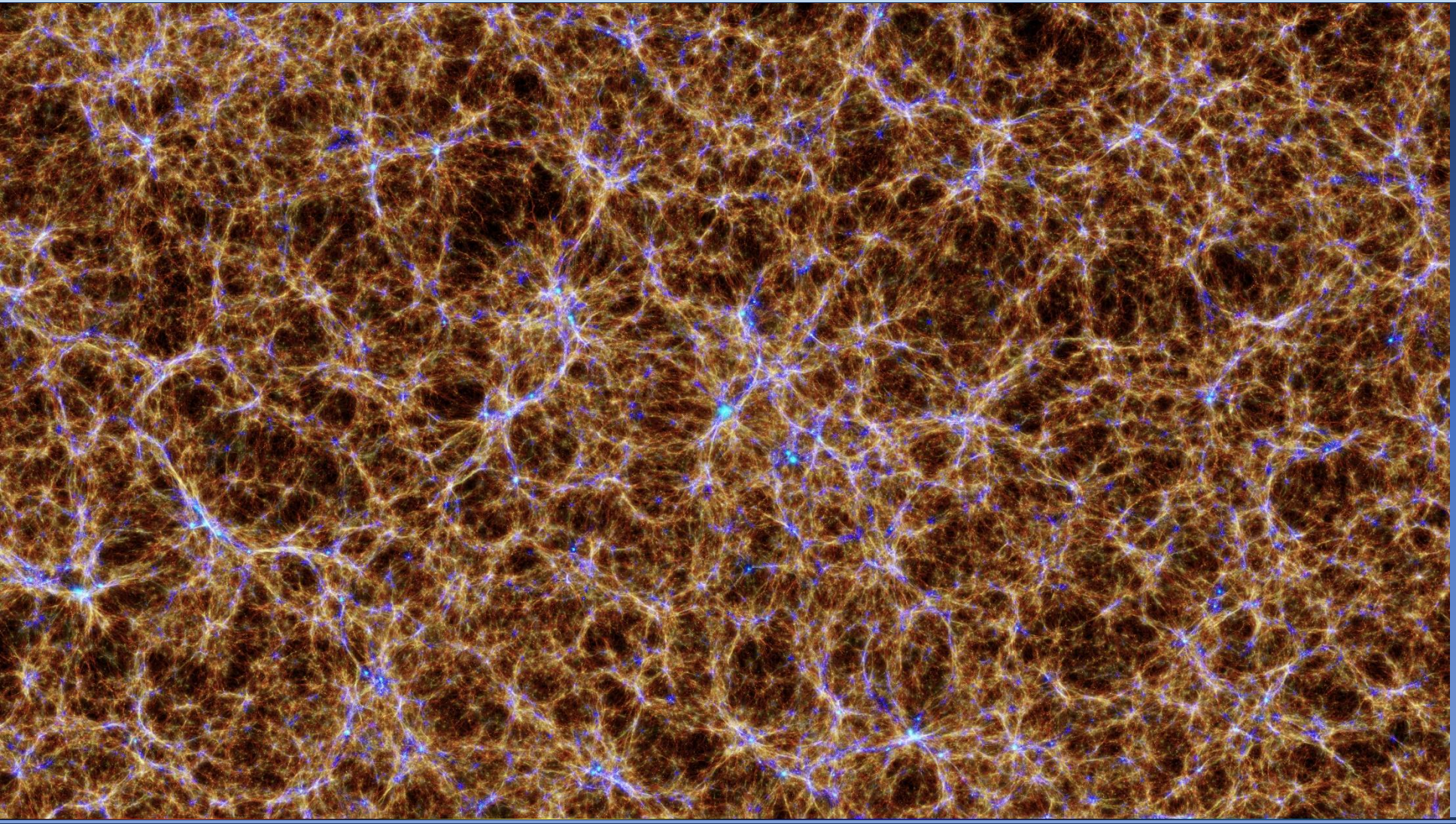
	mr	hr	uhr
m_{DM} $(M_\odot/h)$	$1.3 \cdot 10^{10}$	$6.9 \cdot 10^{8}$	$3.7 \cdot 10^{7}$
m_{Gas} $(M_\odot/h)$	$2.6 \cdot 10^{9}$	$1.4 \cdot 10^{7}$	$7.3 \cdot 10^{6}$

One gas particle can spawn up to 4 stellar particles.

- Modified SPH version of GADGET-3 (incl. thermal conduction)
- Feedback from stellar winds
- Feedback from AGN
- Metal enrichment and star formation follow pattern of metal production from SNIa, SNII & AGB
- Gas cooling depends on local metallicity

Web-Portal:
c2papcosmosim.srv.lrz.de

Ragagnin et al., 2017

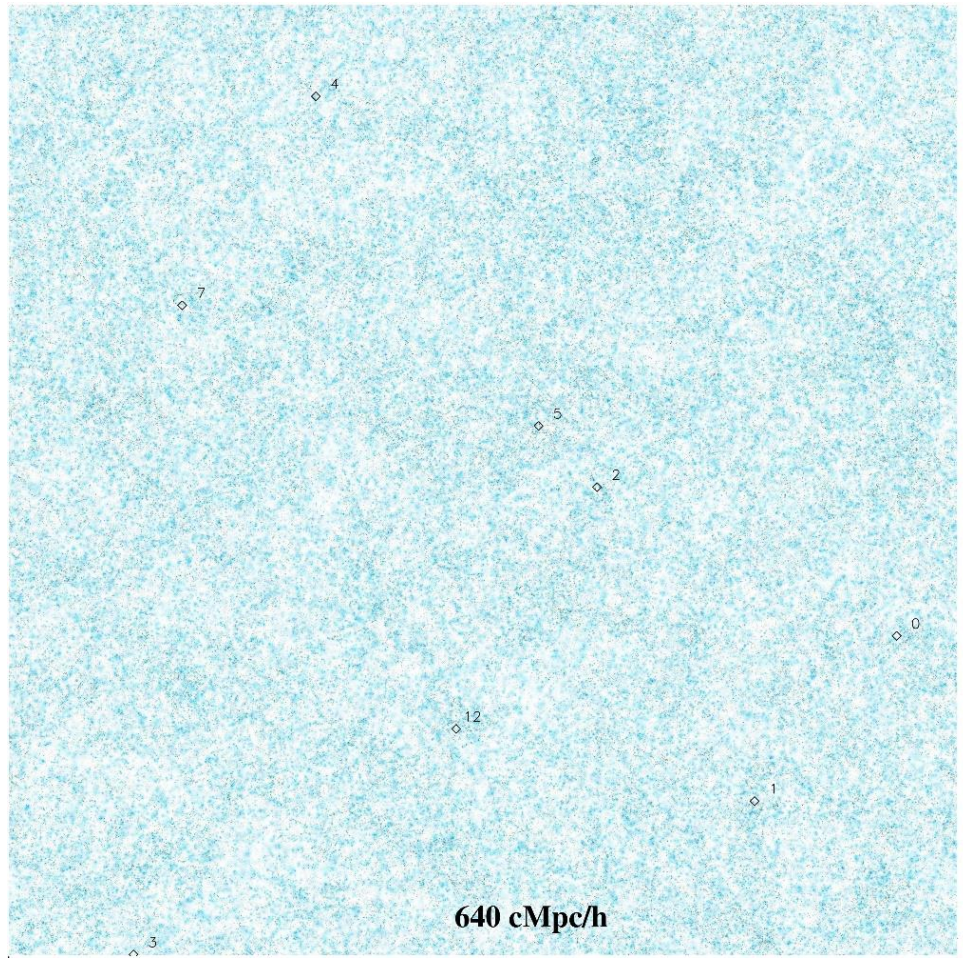


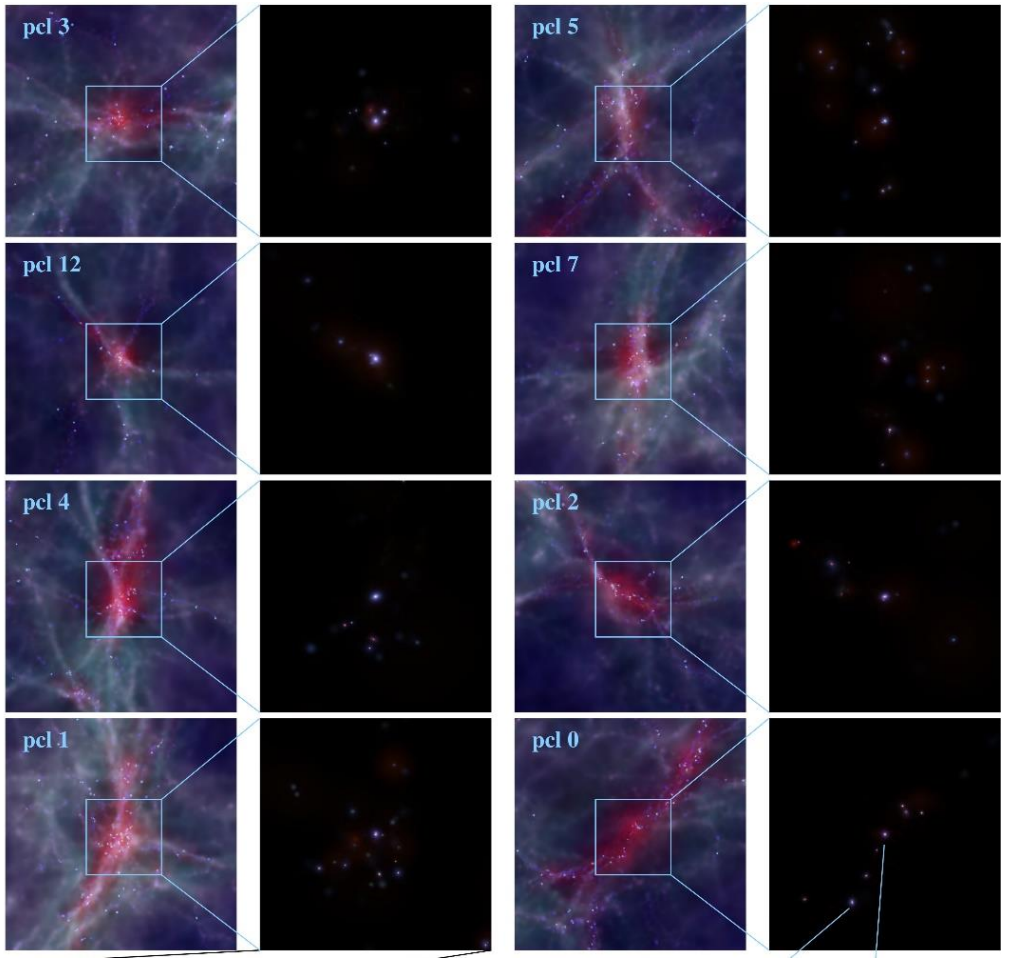
Magneticum Box2b-Simulation:
640 Mpc/h,
$m_{DM}\ (M_\odot/h) = 6.9{\cdot}10^8$

Millenium-Simulation:
500 Mpc/h,
$m_{DM}\ (M_\odot/h) = 8{\cdot}10^8$

TNG300:
300 Mpc/h,
$m_{DM}\ (M_\odot/h) = 6{\cdot}10^7$

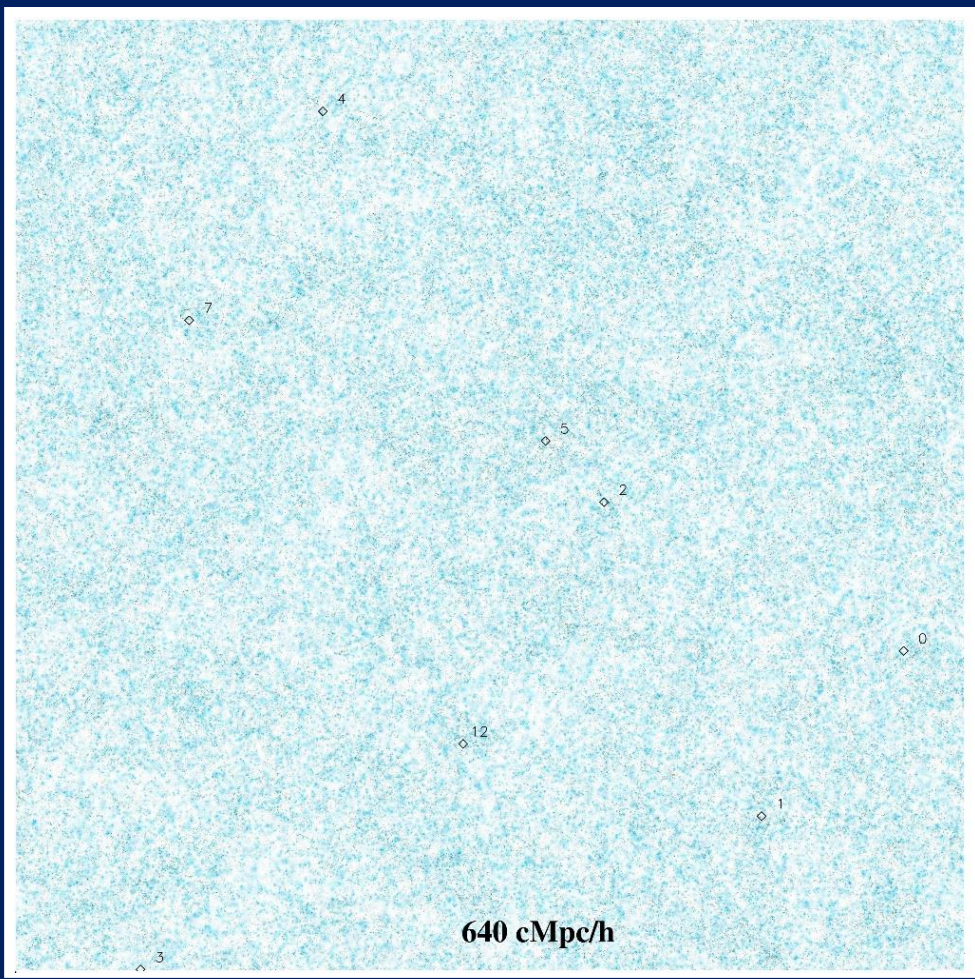
Protocluster in Magneticum

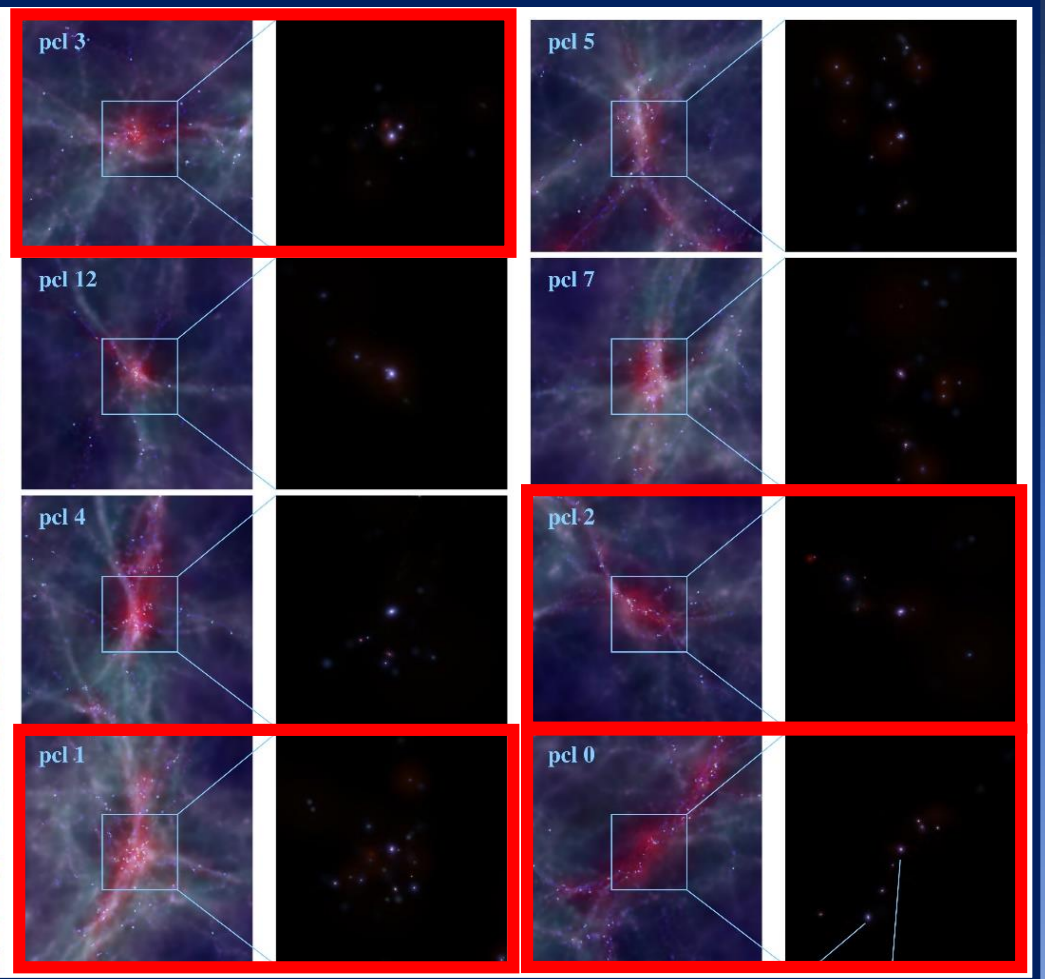




42 potential Protocluster with $M_{vir} > 10^{13} M_{\odot}$

Protocluster in Magneticum



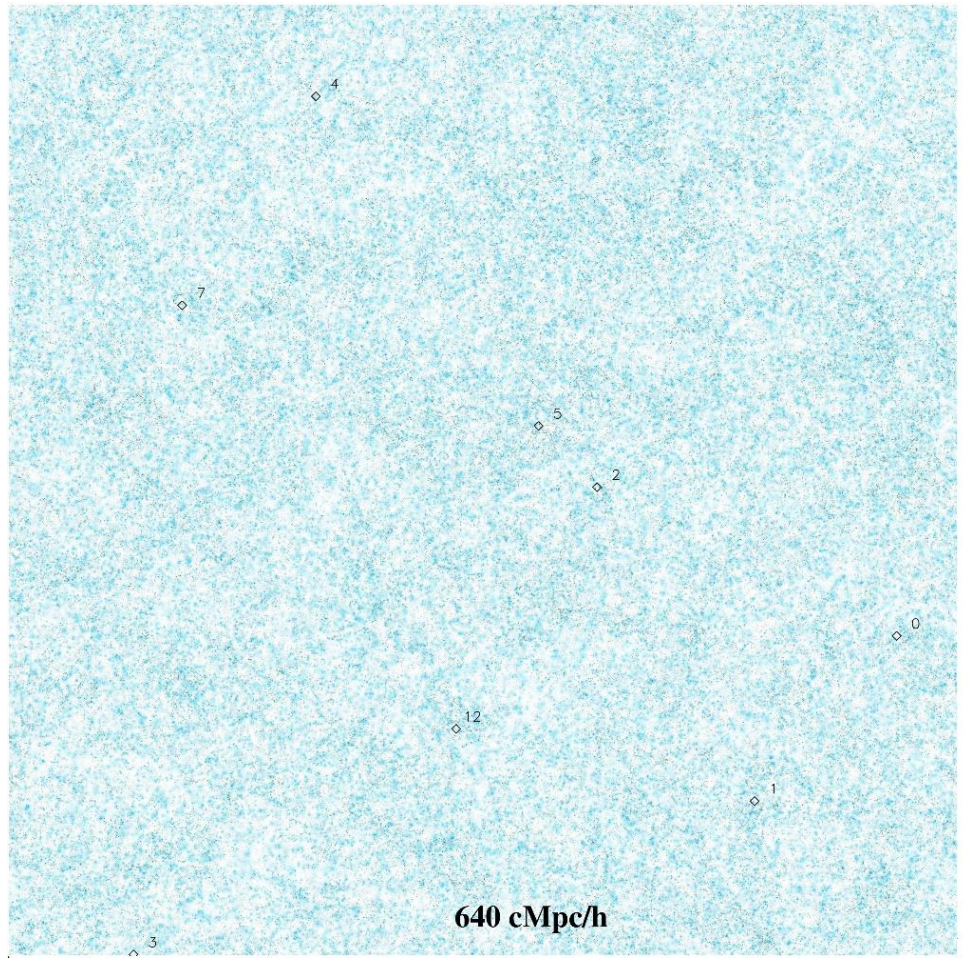


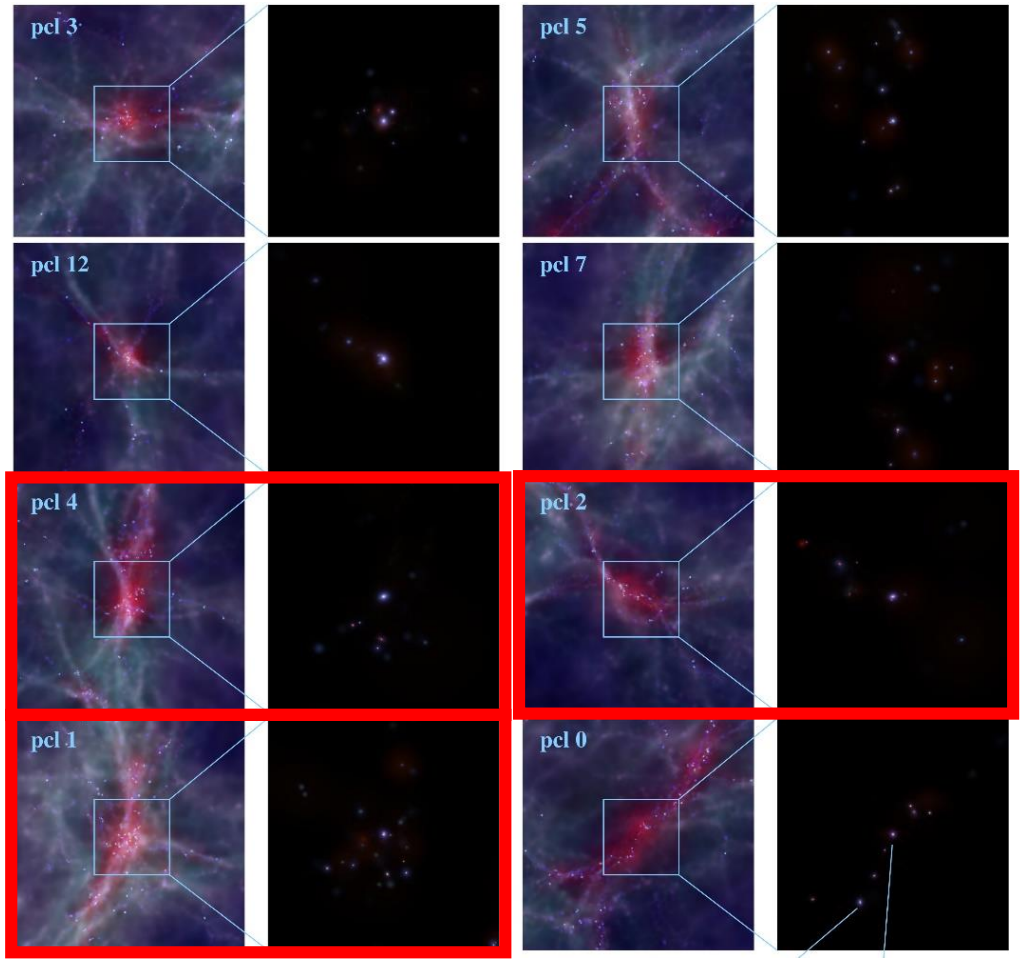
42 potential Protocluster with $M_{vir} > 10^{13} M_{\odot}$

Different selection criteria:

- Most massive M_{vir}

Protocluster in Magneticum



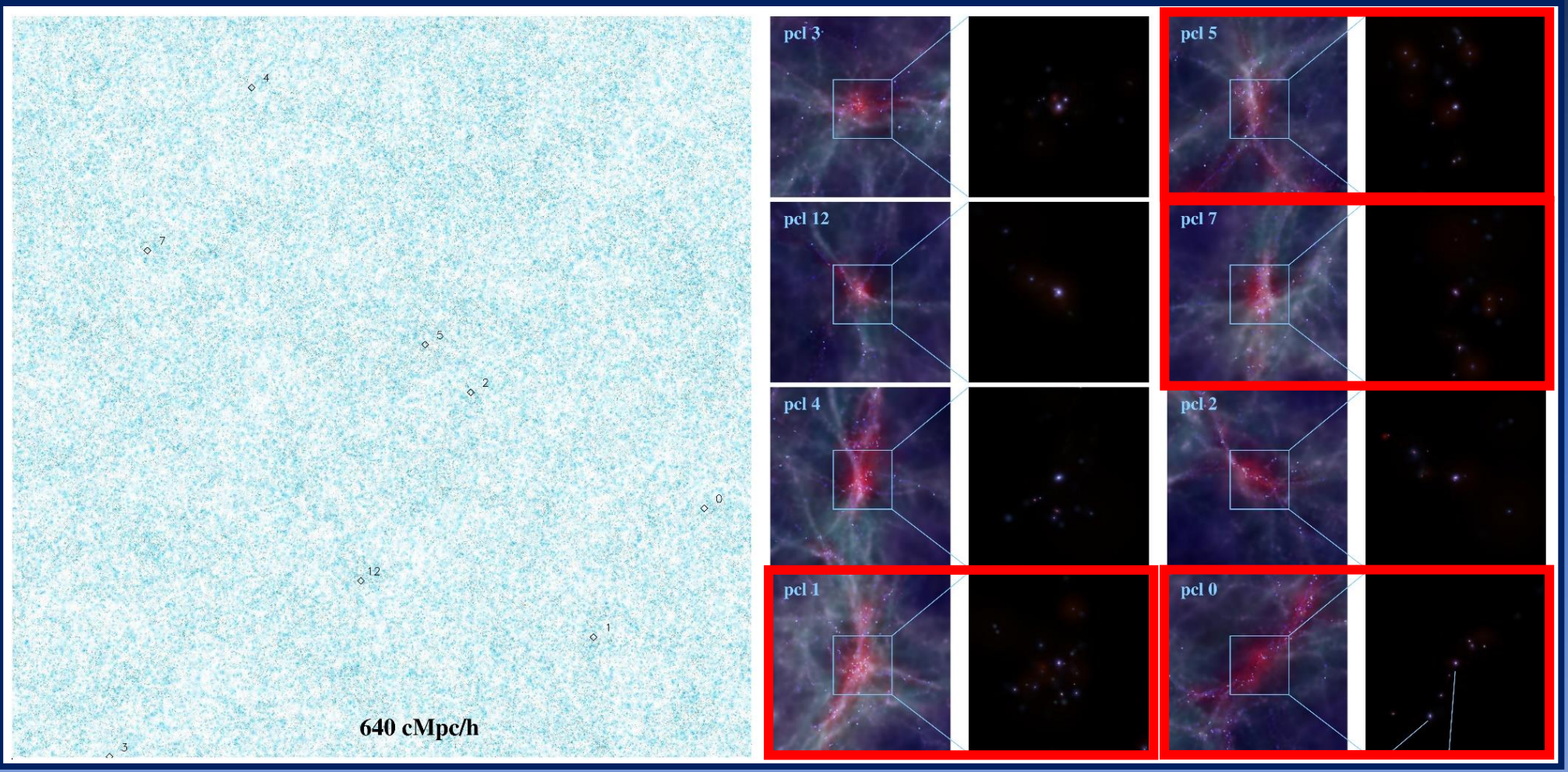


42 potential Protocluster with $M_{vir} > 10^{13} M_{\odot}$

Different selection criteria:

- Most massive M_{vir}
- Most massive M_{Gal}

Protocluster in Magneticum

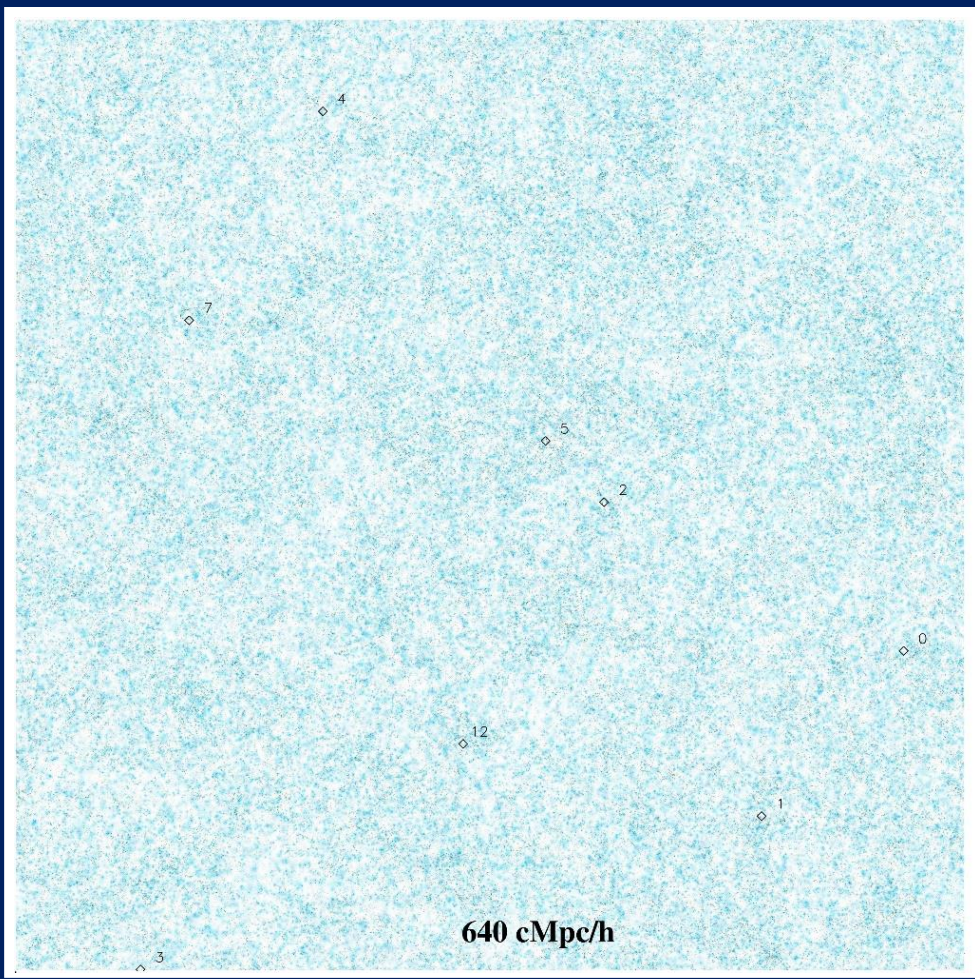


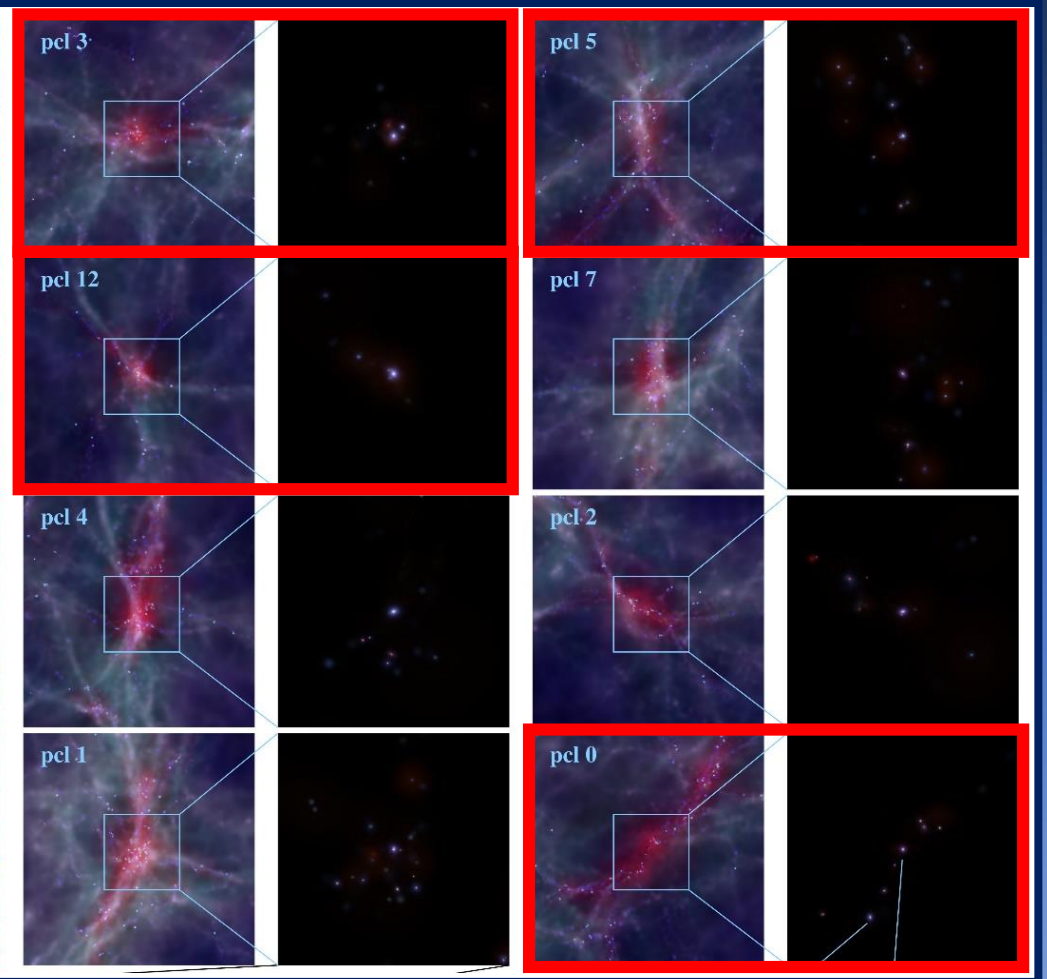
42 potential Protocluster with $M_{vir} > 10^{13} M_{\odot}$

Different selection criteria:

- Most massive M_{vir}
- Most massive M_{Gal}
- Richest N_{Gal}

Protocluster in Magneticum



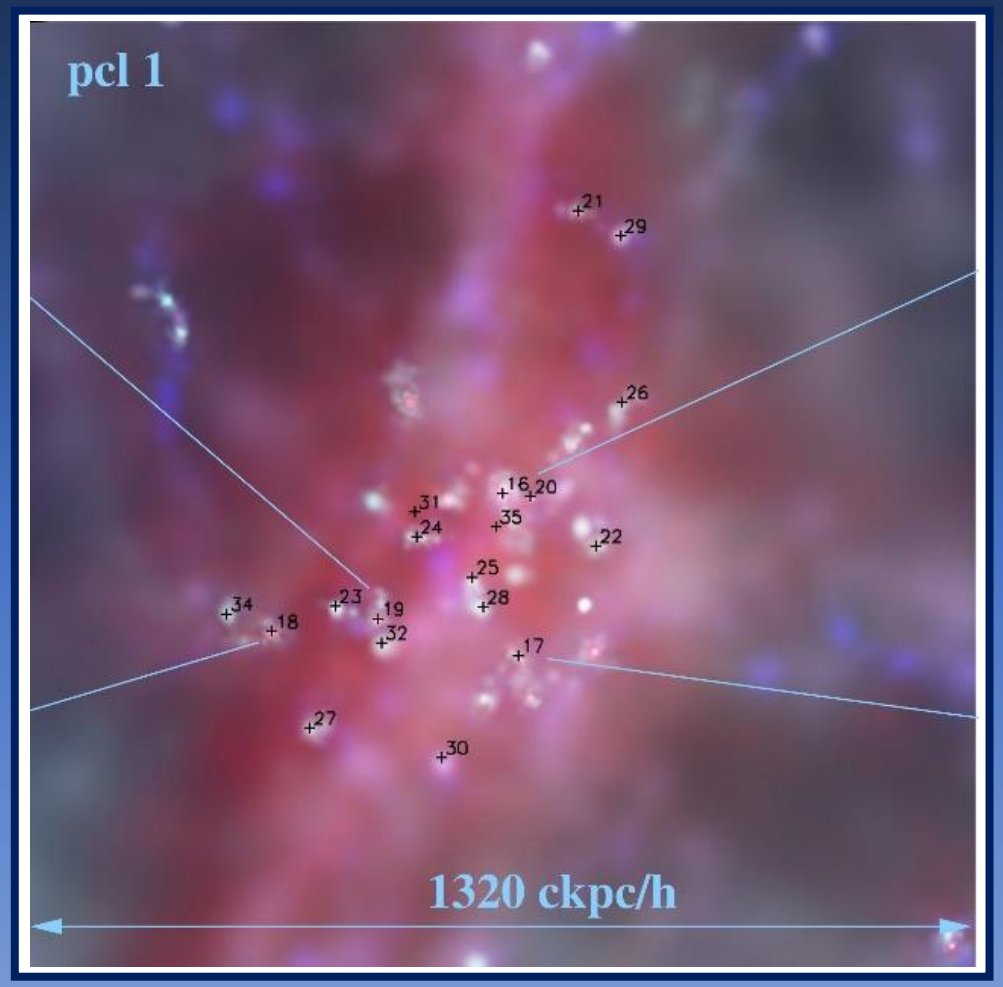


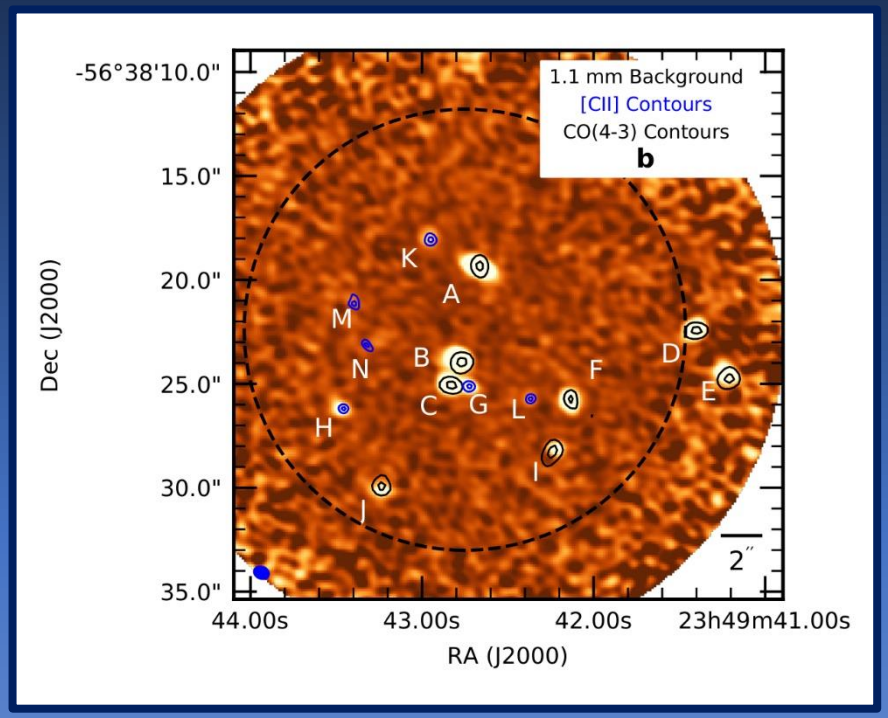
42 potential Protocluster with $M_{vir} > 10^{13} M_{\odot}$

Different selection criteria:

- Most massive M_{vir}
- Most massive M_{Gal}
- Richest N_{Gal}
- Most star forming

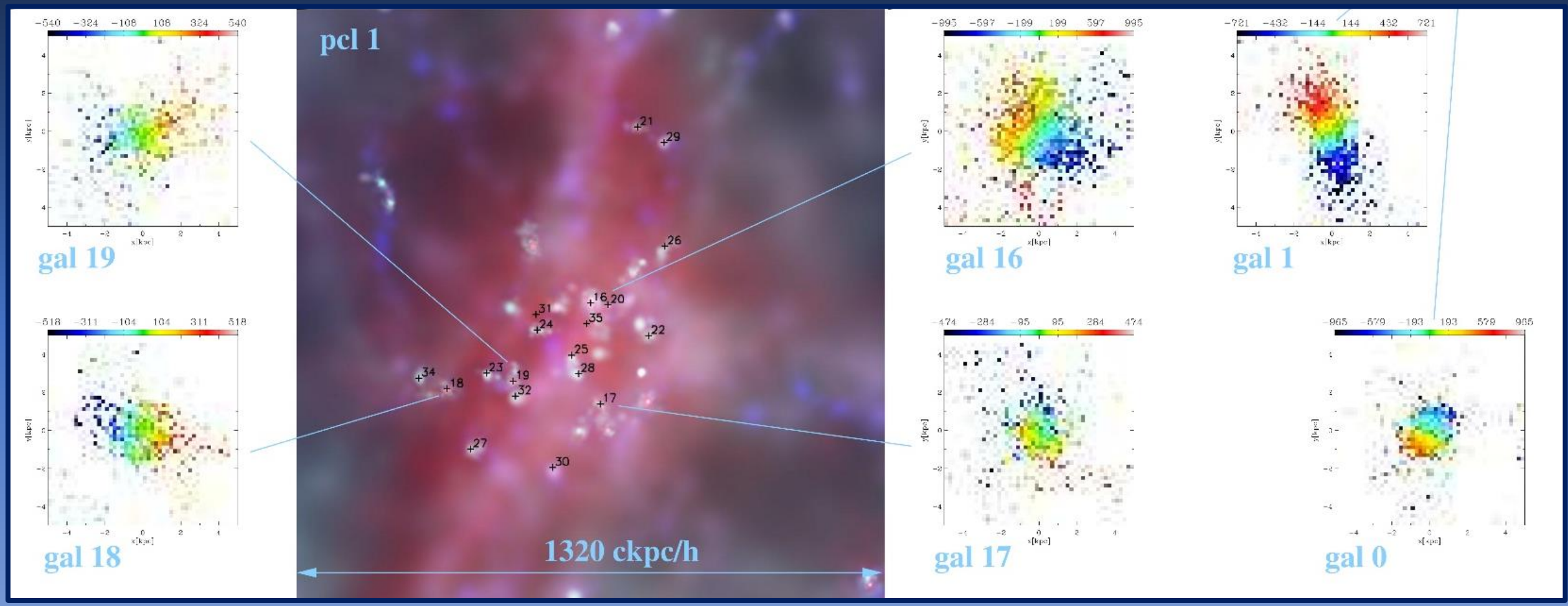
Protocluster in Magneticum



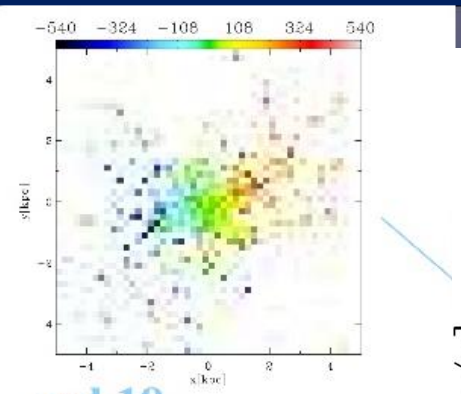


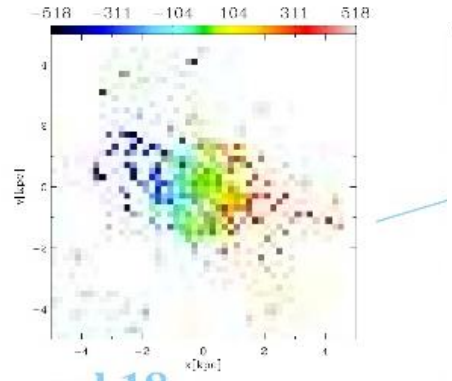
Miller et al., 2018

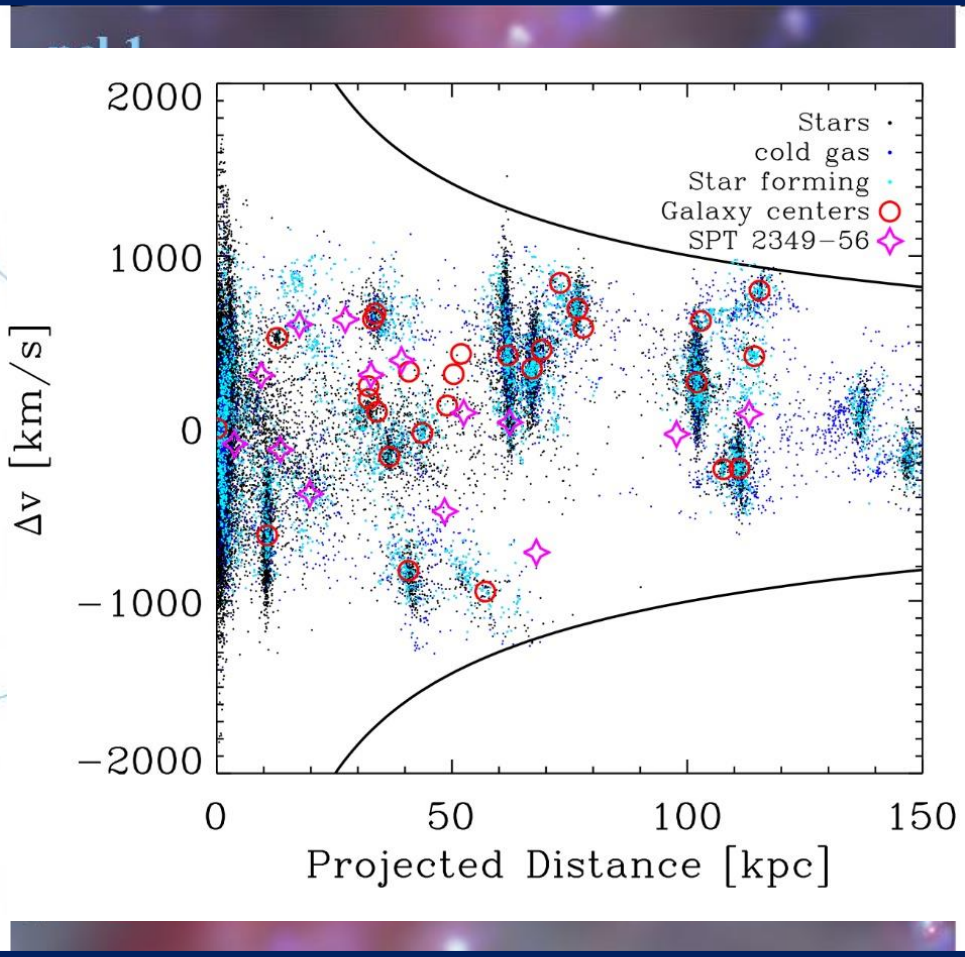
Protocluster in Magneticum

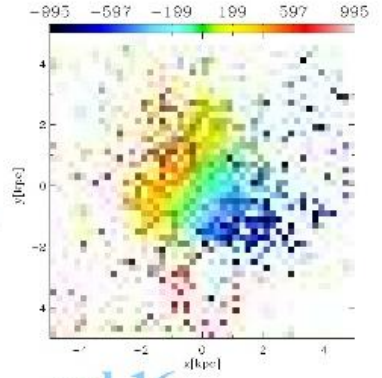


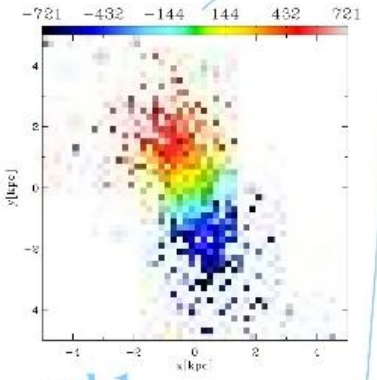
Protocluster in Magneticum

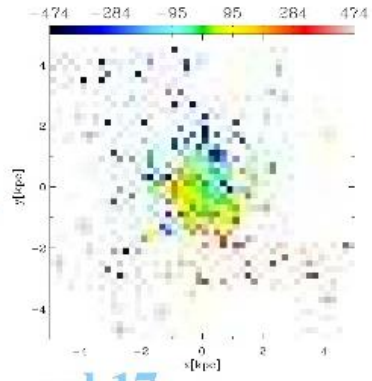


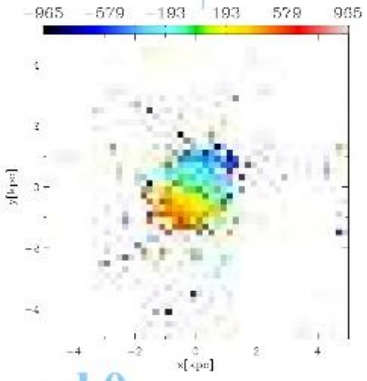




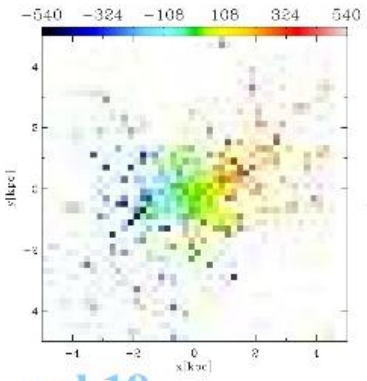


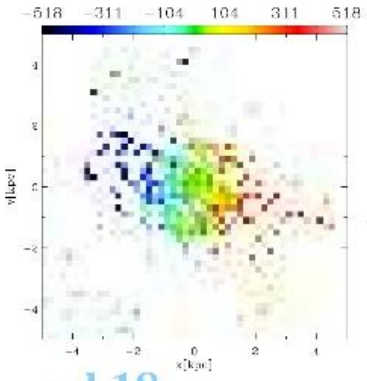


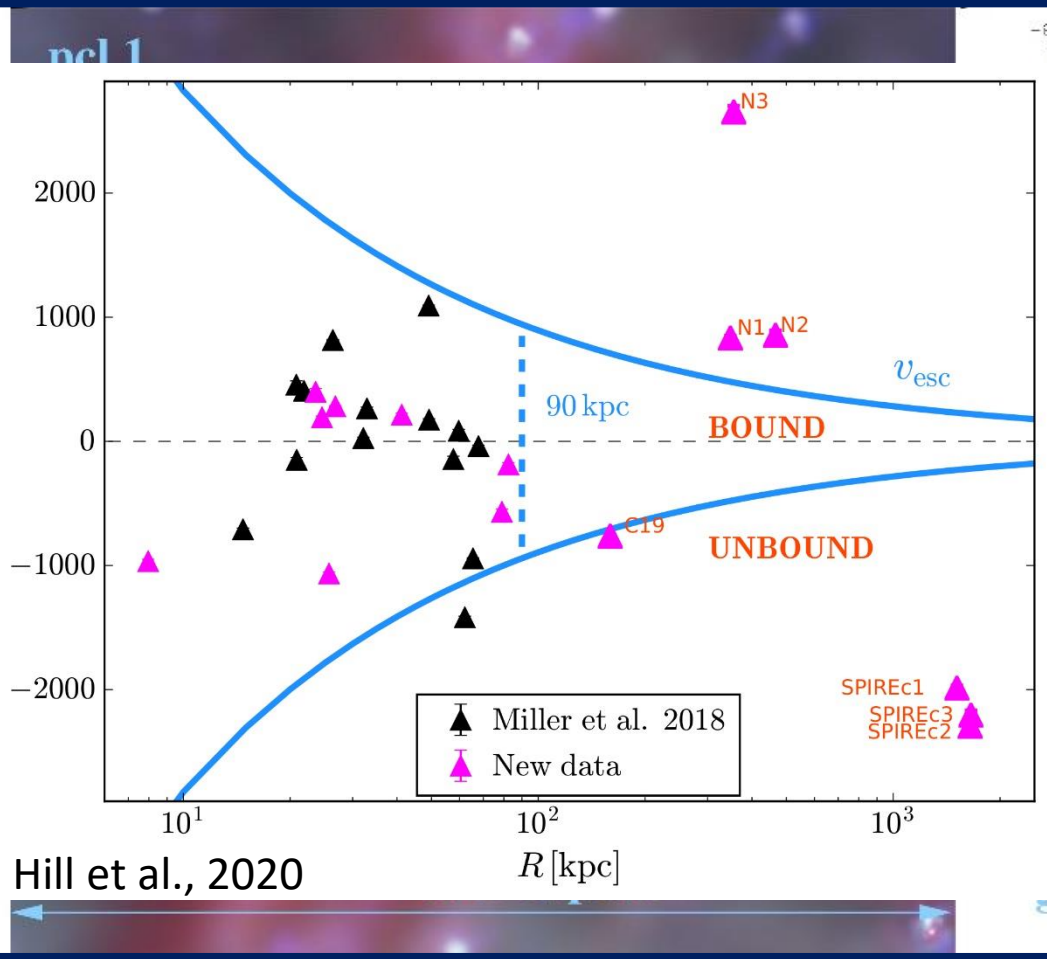




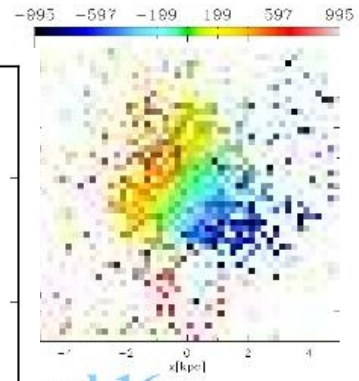
Protocluster in Magneticum

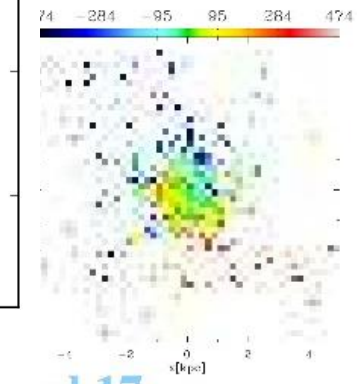


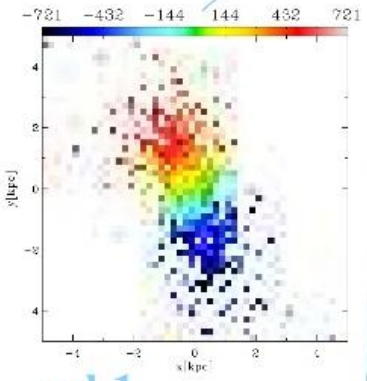


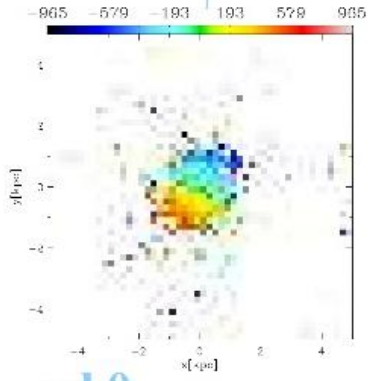


Hill et al., 2020

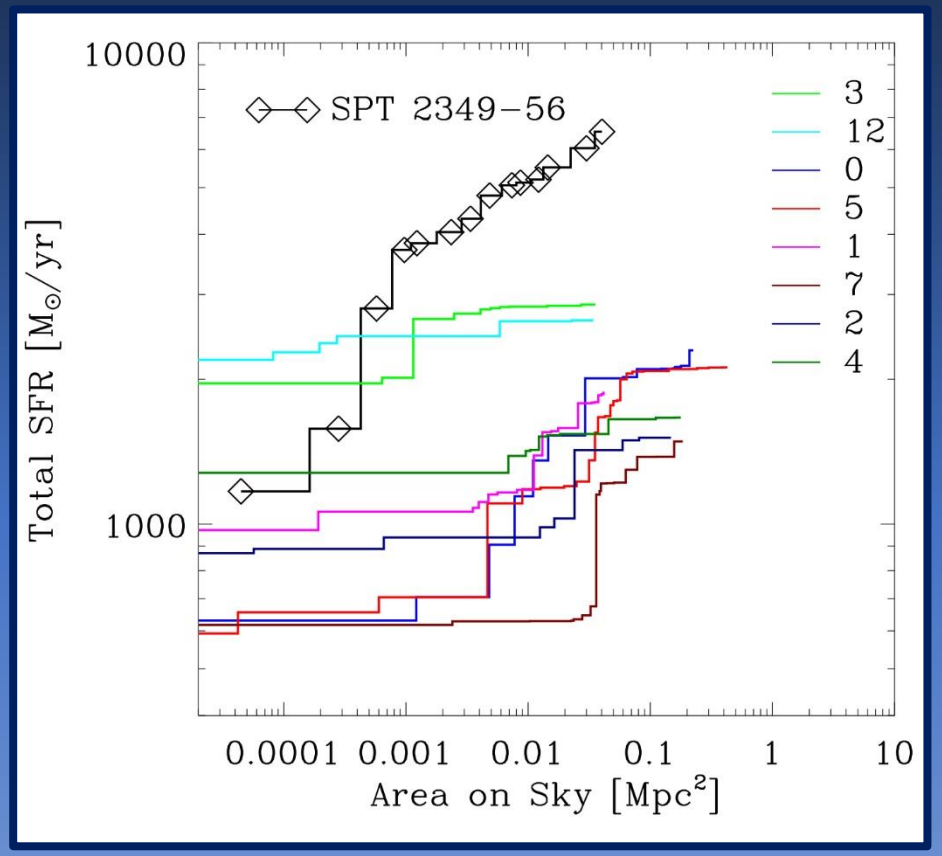


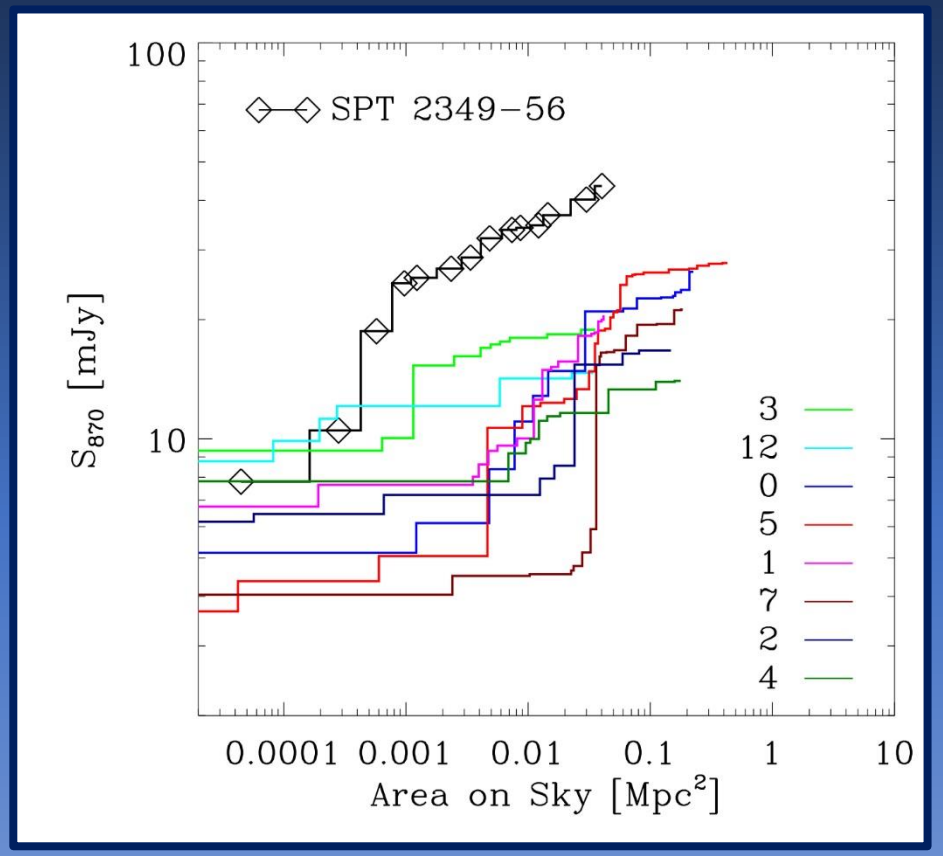






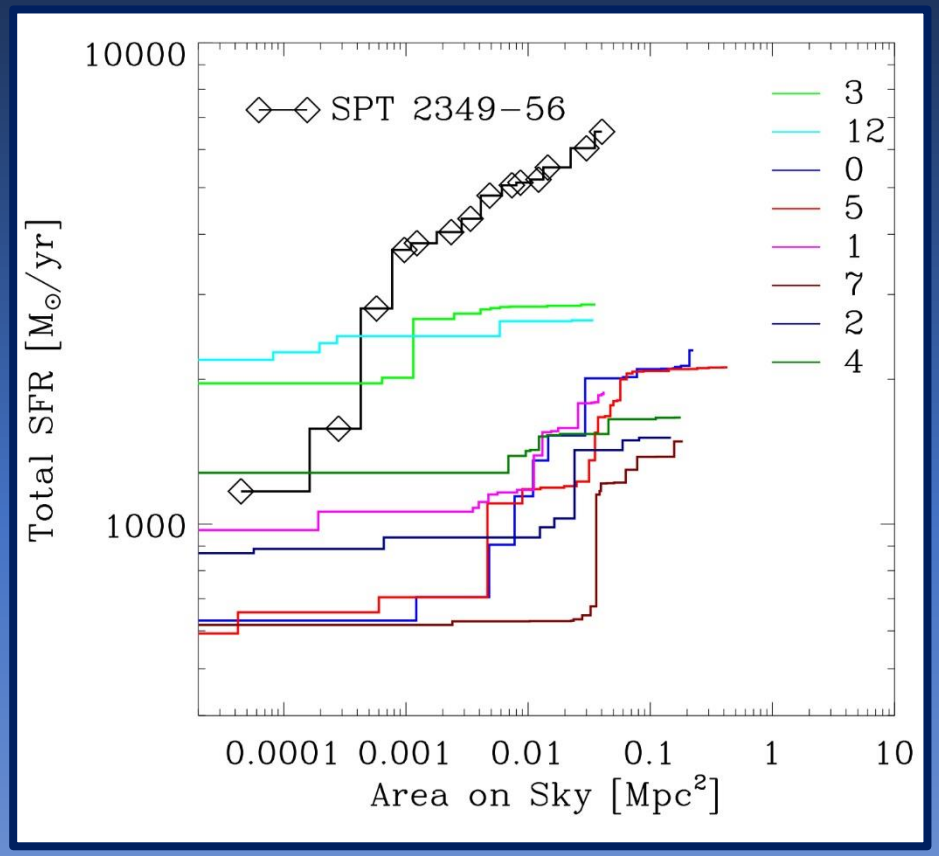
Protocluster in Magneticum: Area on Sky

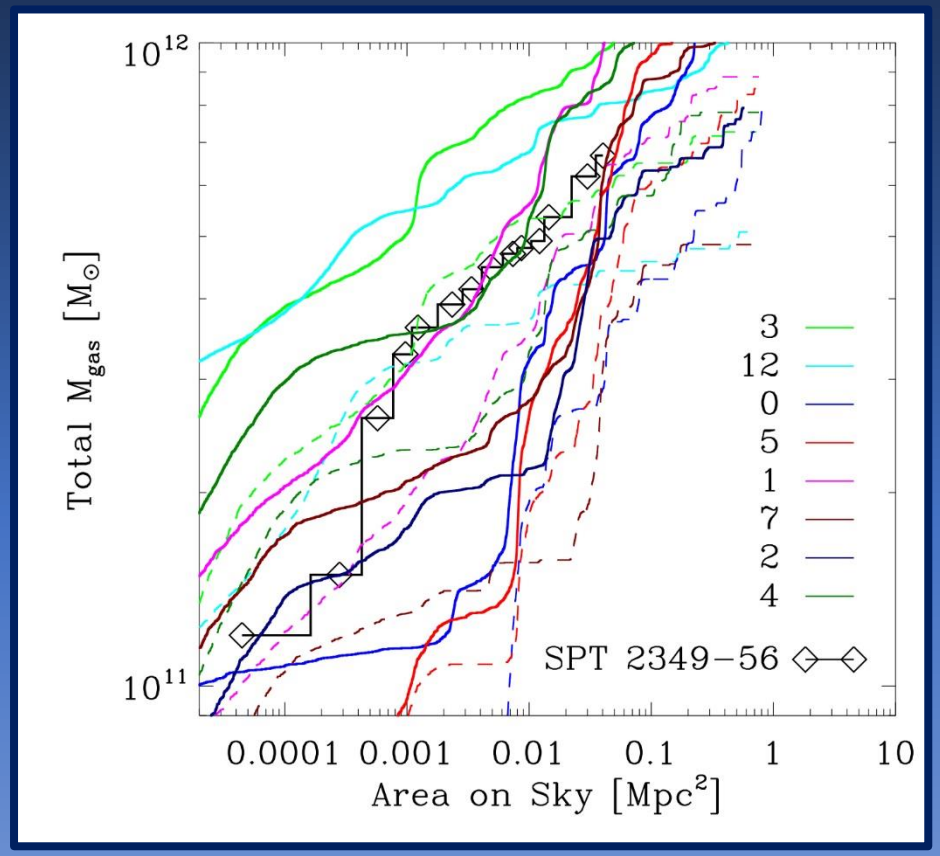




SPT 2349-56:
Miller et al., 2018

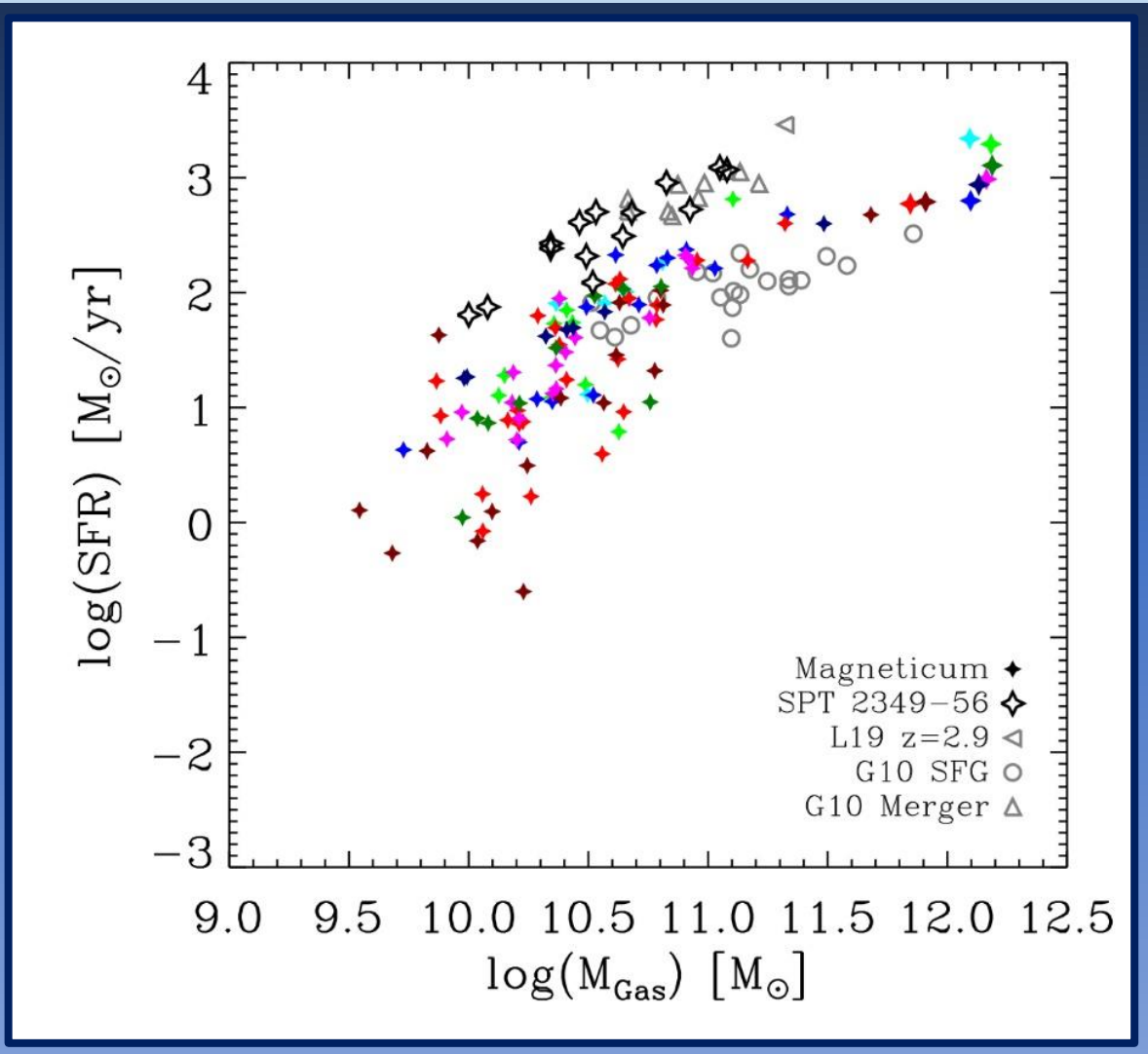
Protocluster in Magneticum: Area on Sky





SPT 2349-56:
Miller et al., 2018

Gas mass versus Star Formation Rate



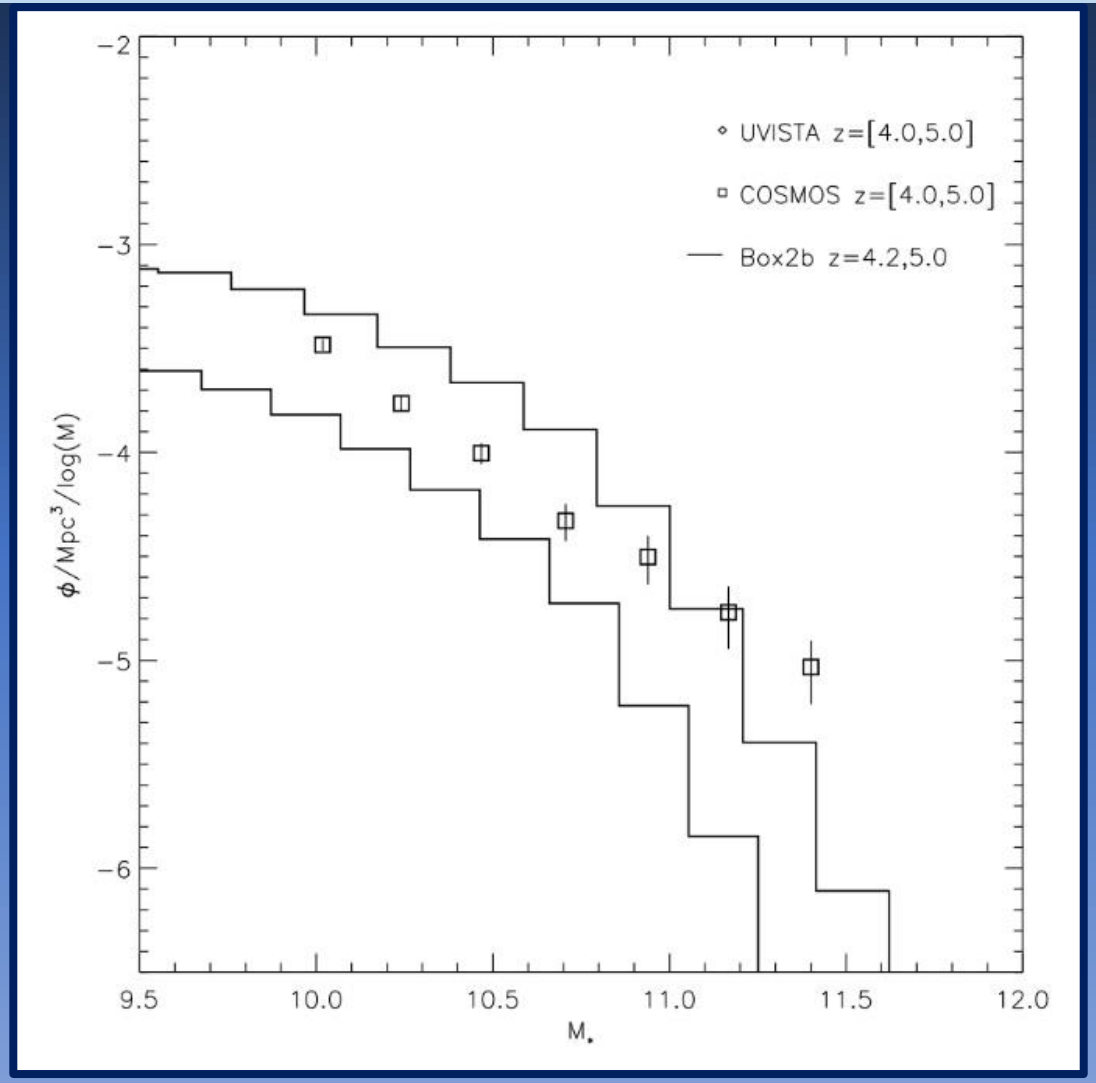
Star formation rate in Magneticum lower than in observed Protocluster galaxies by a factor 2

Either star formation at higher redshifts larger, or star formation more bursty than in our model

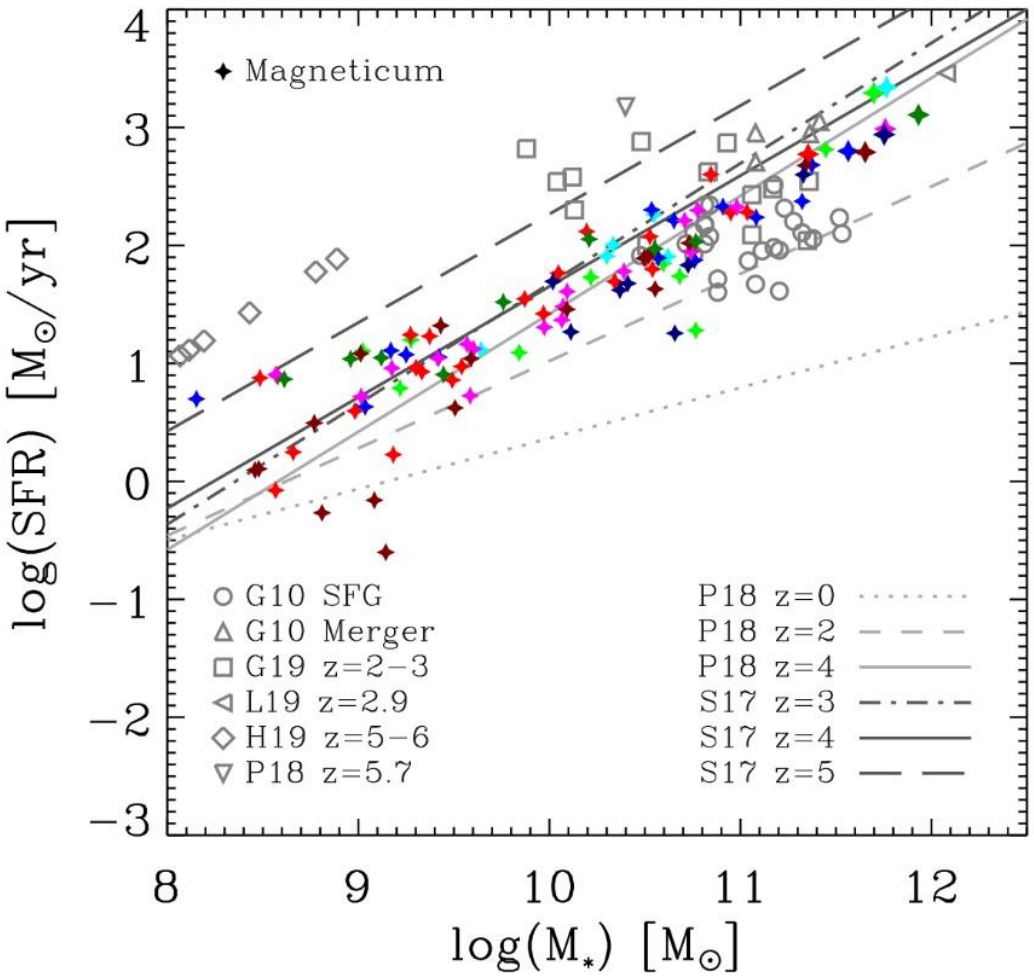
G10: Genzel et al., 2010: Galaxies with 4<z<1
L19: Leung et al., 2019: HXMM05 @ z=2.9

See also Bassini et al., 2020 for SFR in simulated protoclusters from DIANOGA and his Poster

Stellar Mass Function



Star formation main sequence



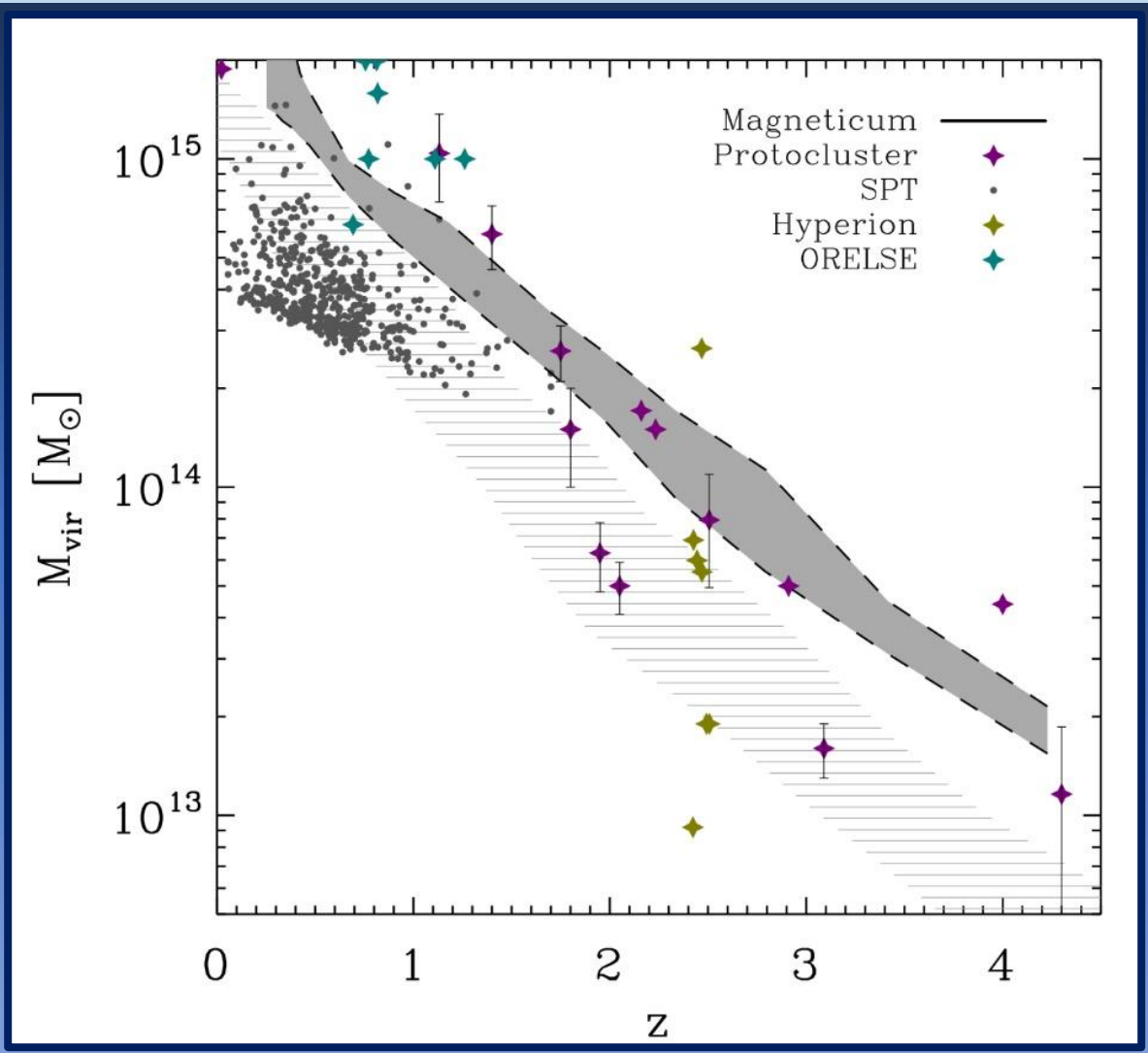
Star formation main sequence well reproduced by Magneticum even at $z \sim 4$

Star formation more bursty than in our model!

See also Bassini et al., 2020 for SFR in simulated protoclusters from DIANOGA and his Poster

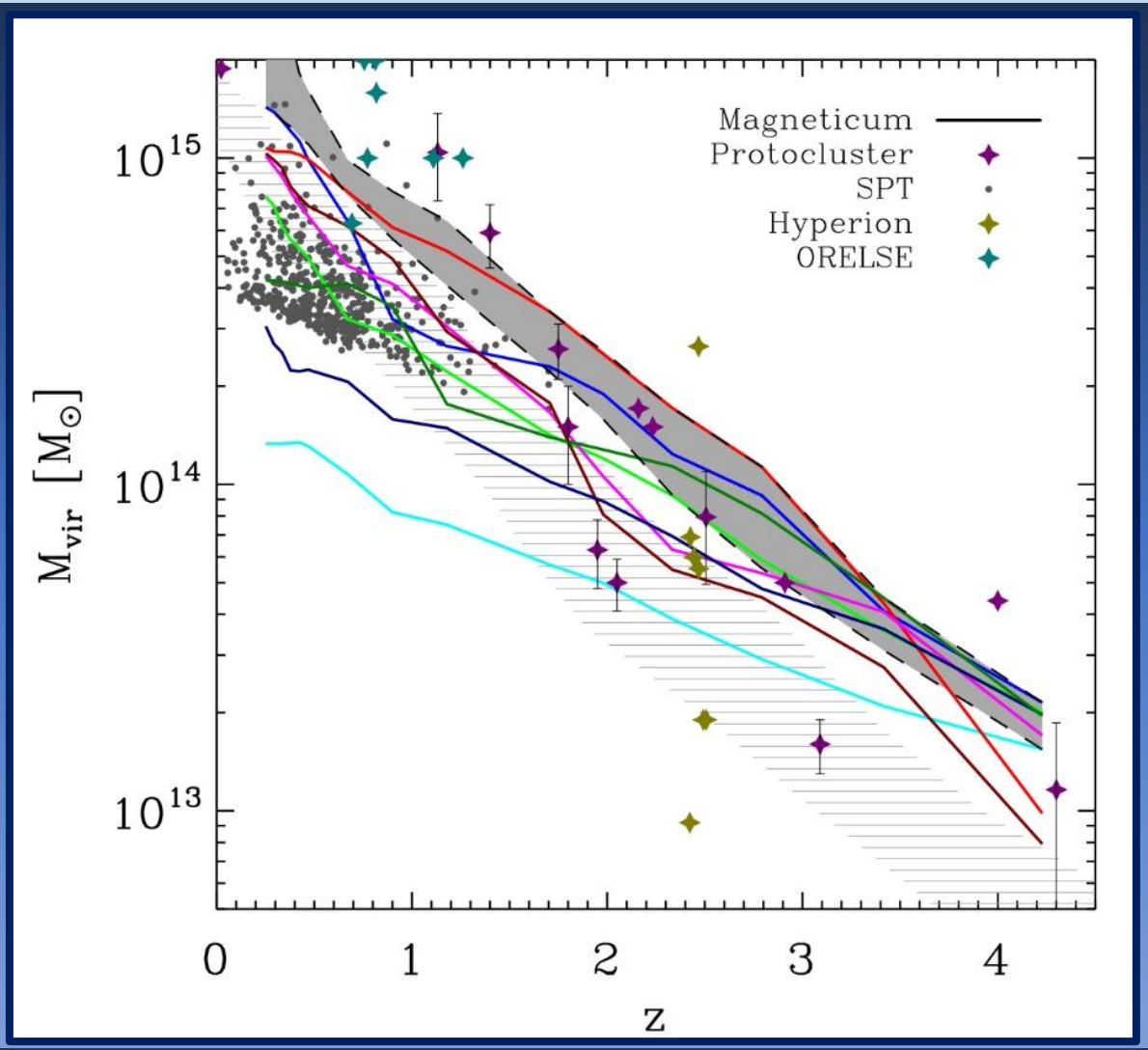
S17: Santini et al., 2017: Hubble frontier field, 6 > z > 1.3
P18: Pearson et al., 2018: Herschel-SPIRE, 6 > z > 0.2
G10: Genzel et al., 2010: Galaxies with 4<z<1
L19: Leung et al., 2019: HXMM05
G19: Gomez-Guijarro et al., 2019: HELAISS02, HXMM20 (z = 2:6), CL J1001+0220
P18: Pavesi et al., 2018: CRLE
H19: Harikane et al., 2019: Silverrush

Protocluster in Magneticum: Evolution



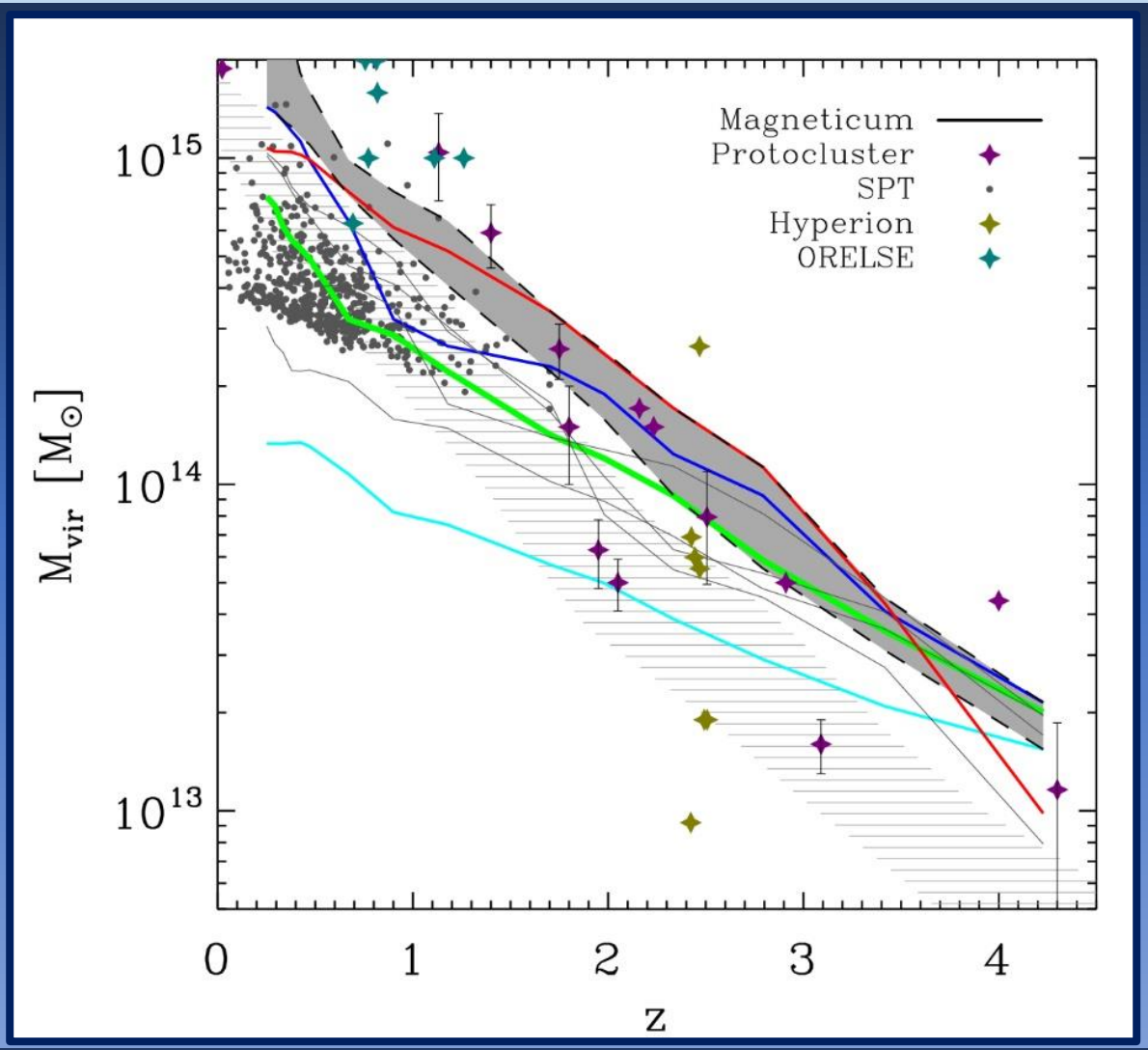
Shade: Magneticum Most Massive at each redshift
Striped: Millenium prediction, Chiang et al., 2013

Protocluster in Magneticum: Evolution



Colored lines: Magneticum Protoclusters
Shade: Magneticum Most Massive at each redshift
Striped: Millenium prediction, Chiang et al., 2013

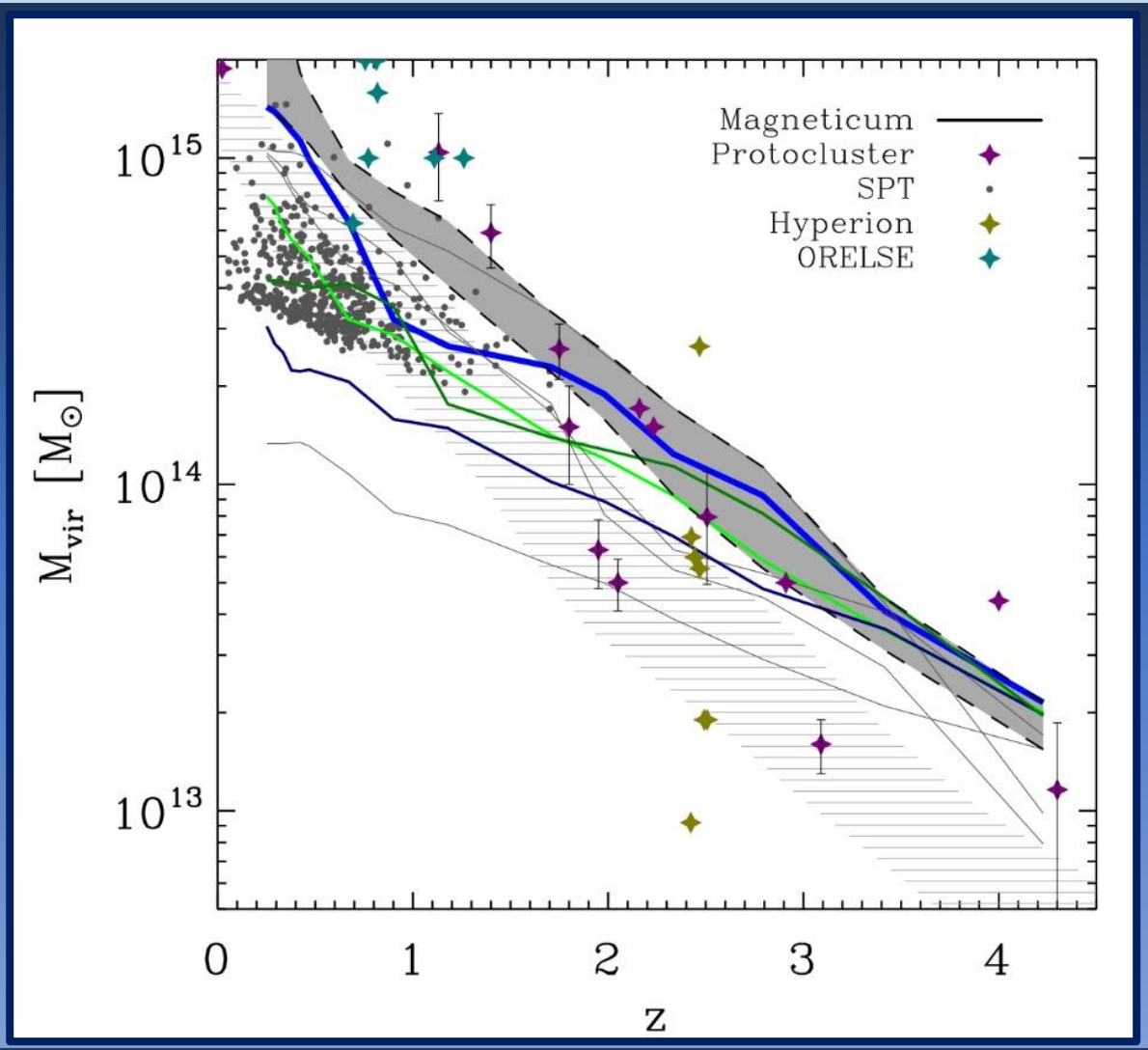
Protocluster in Magneticum: Evolution



Protoclusters: Most Star Forming

Shade: Magneticum Most Massive at each redshift
Striped: Millenium prediction, Chiang et al., 2013

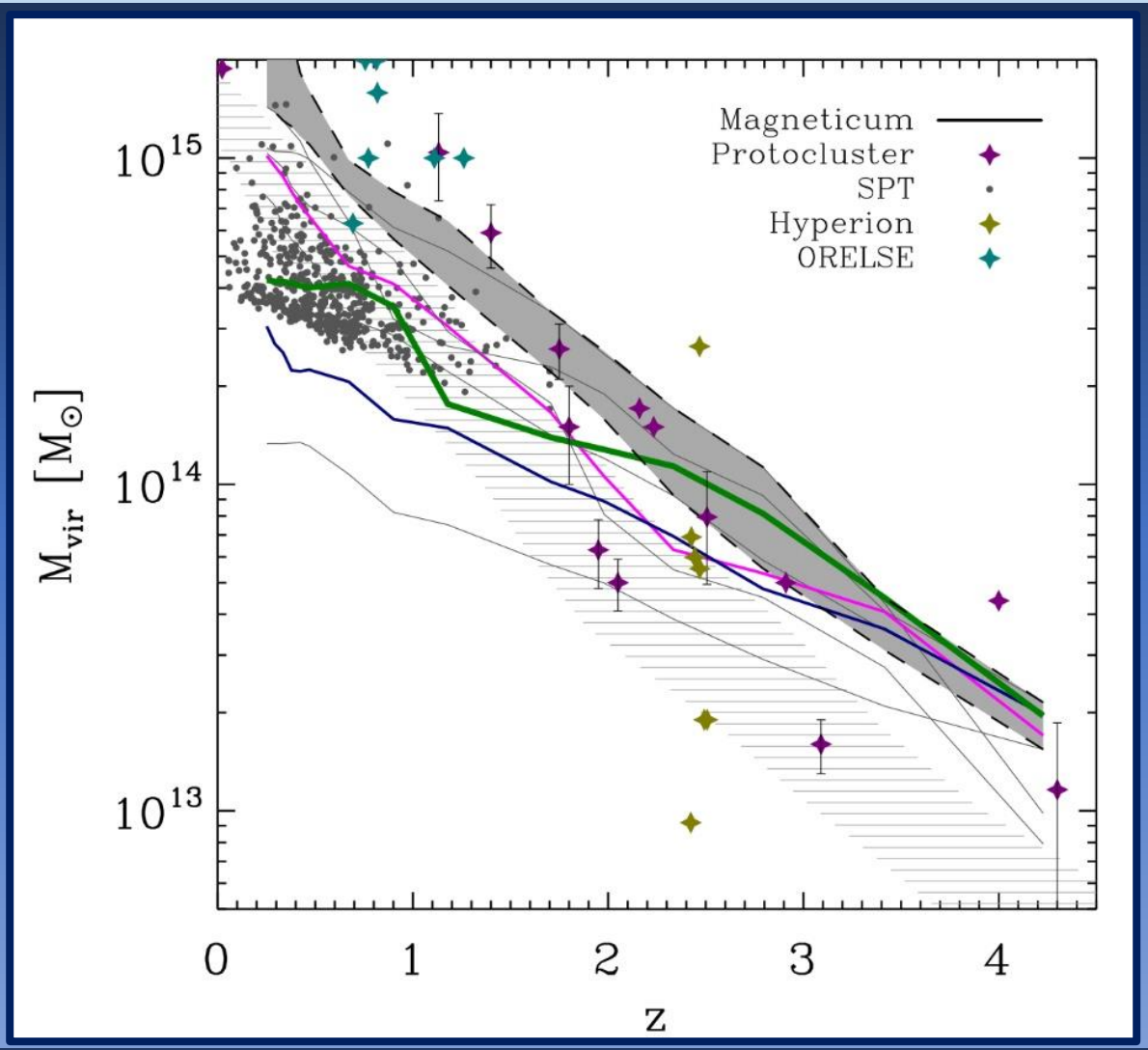
Protocluster in Magneticum: Evolution



Protoclusters: Most Total Mass

Shade: Magneticum Most Massive at each redshift
Striped: Millenium prediction, Chiang et al., 2013

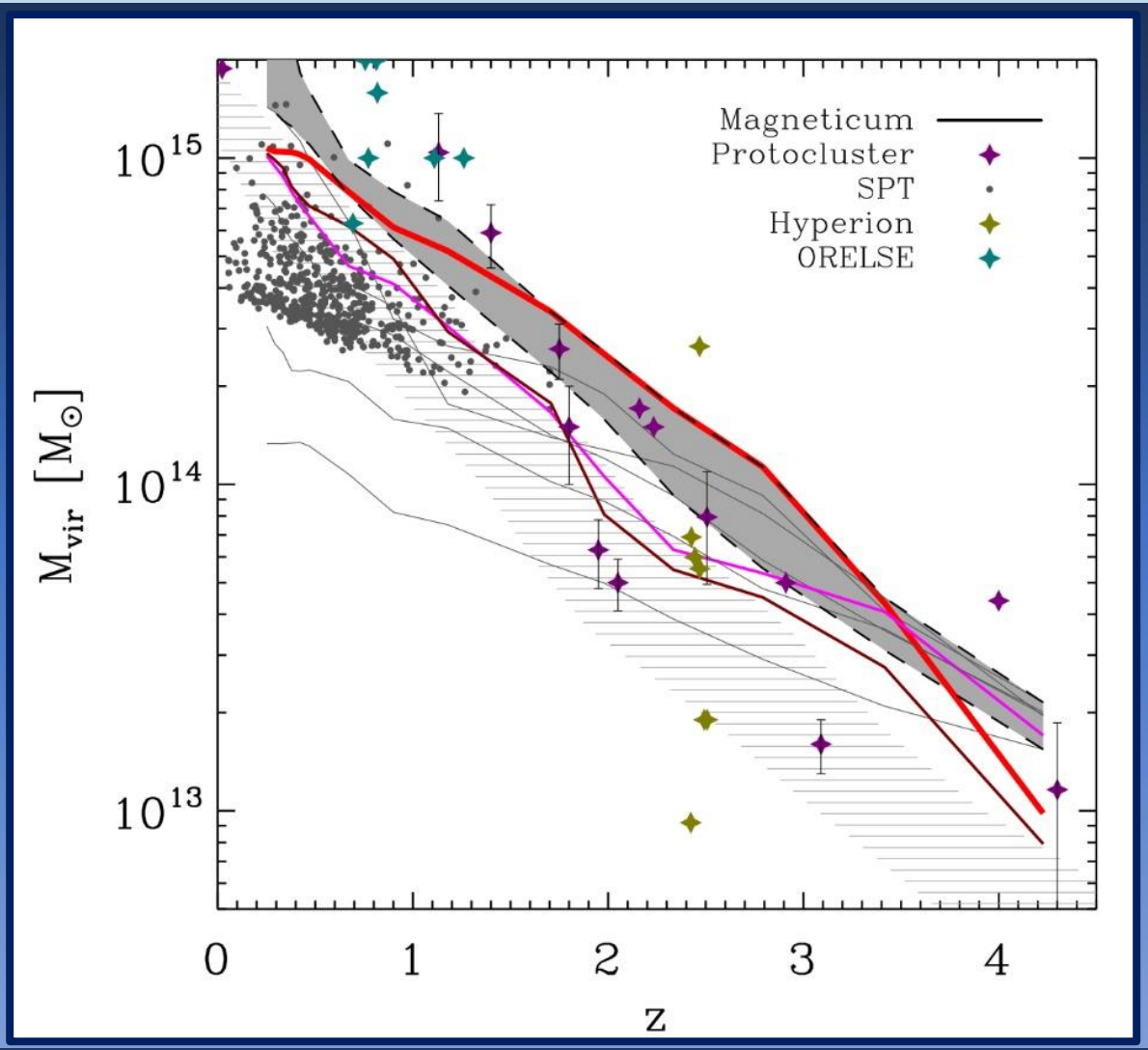
Protocluster in Magneticum: Evolution



Protoclusters: Most Massive Galaxy

Shade: Magneticum Most Massive at each redshift
Striped: Millenium prediction, Chiang et al., 2013

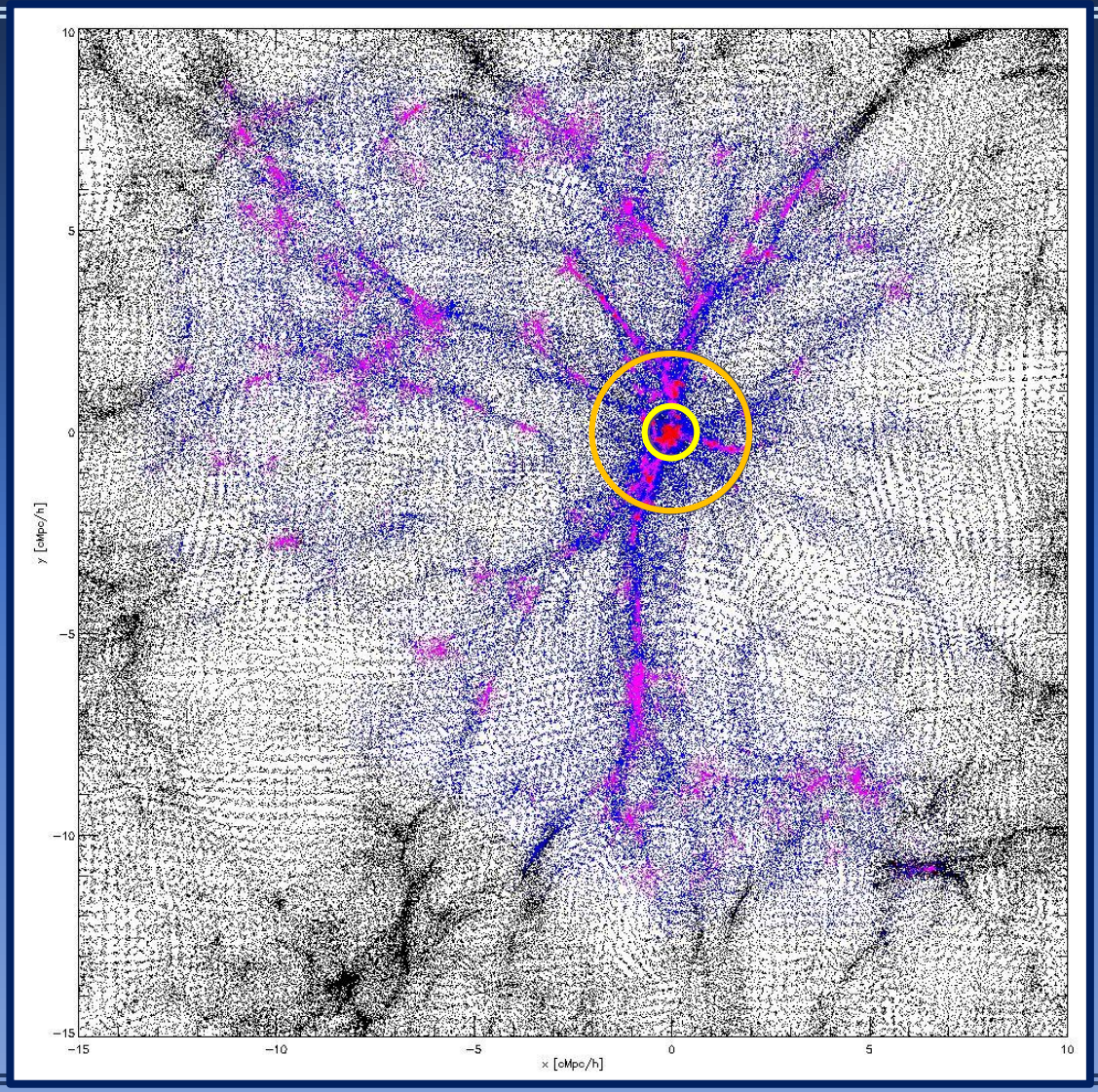
Protocluster in Magneticum: Evolution



Protoclusters: Richest Clusters!

Shade: Magneticum Most Massive at each redshift
Striped: Millenium prediction, Chiang et al., 2013

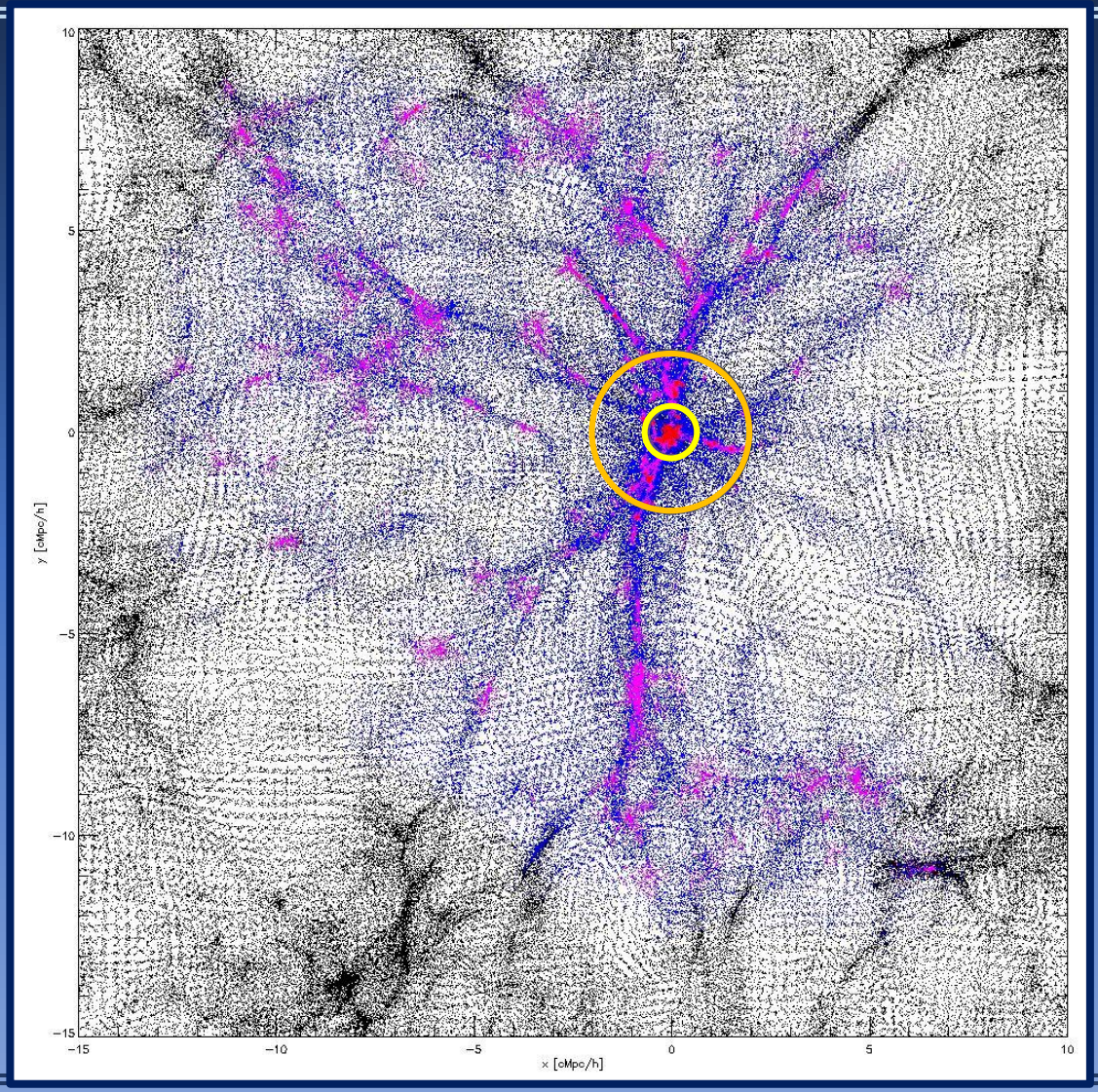
Protocluster in Magneticum: Evolution

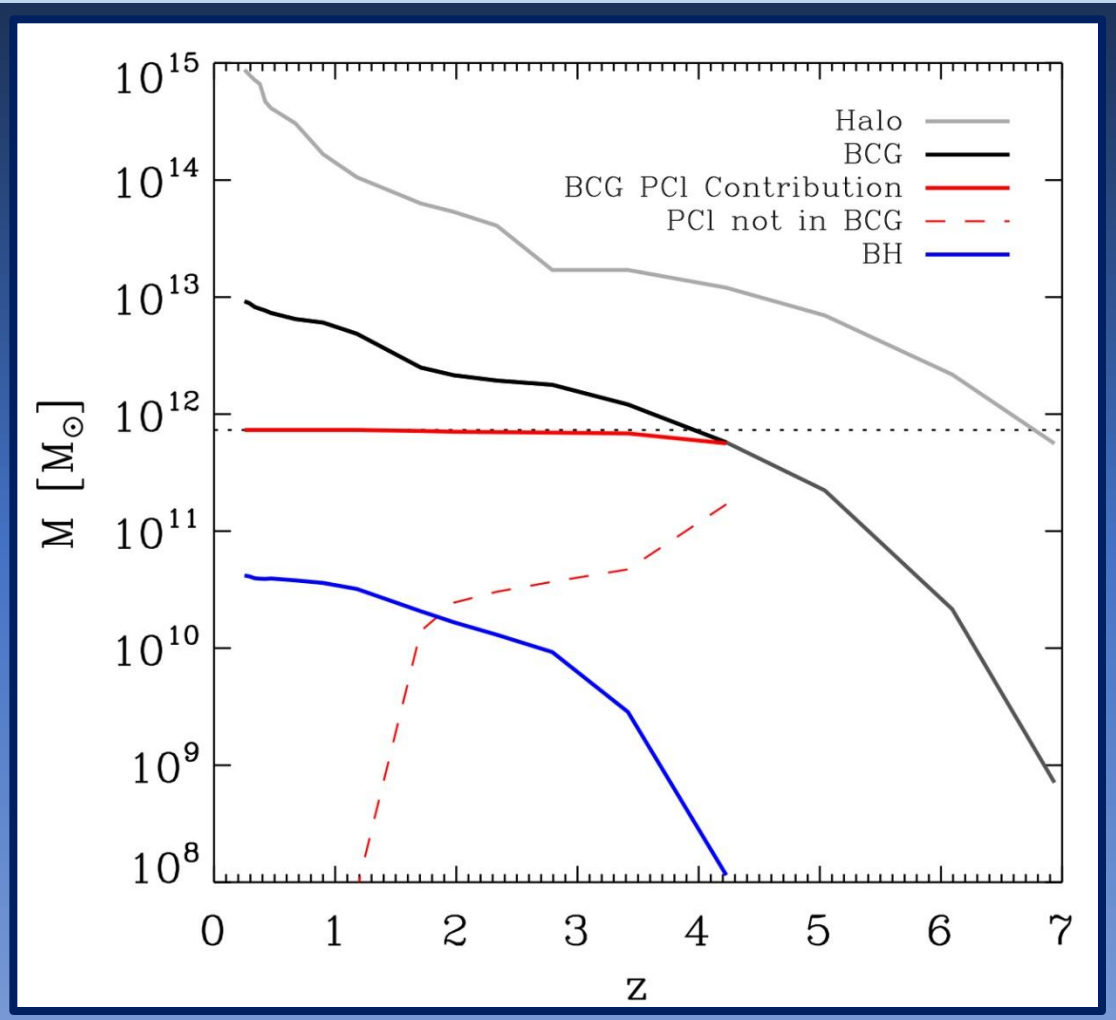


R_{vir} @ z = 4.3

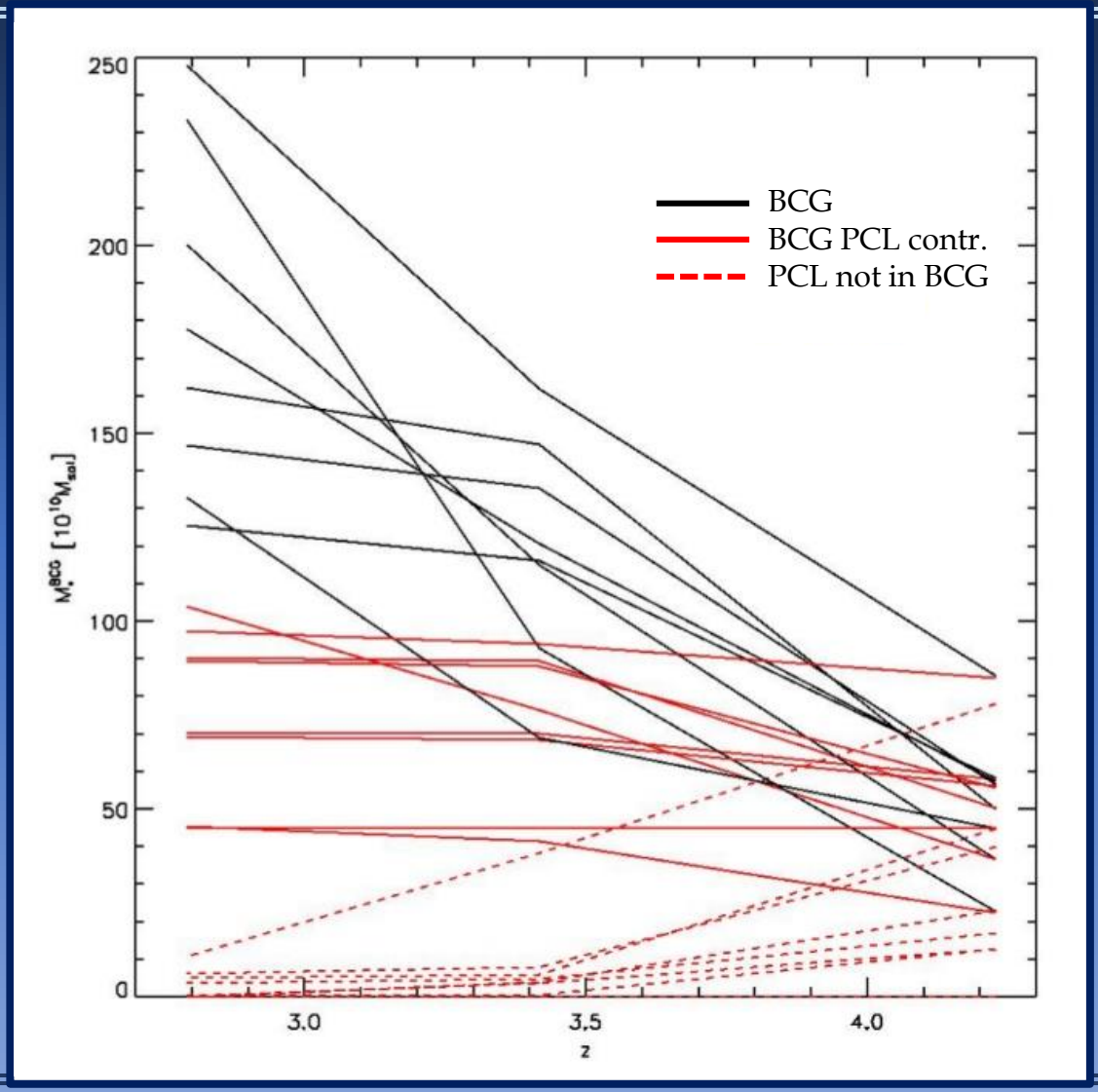
R_{vir} @ z = 0

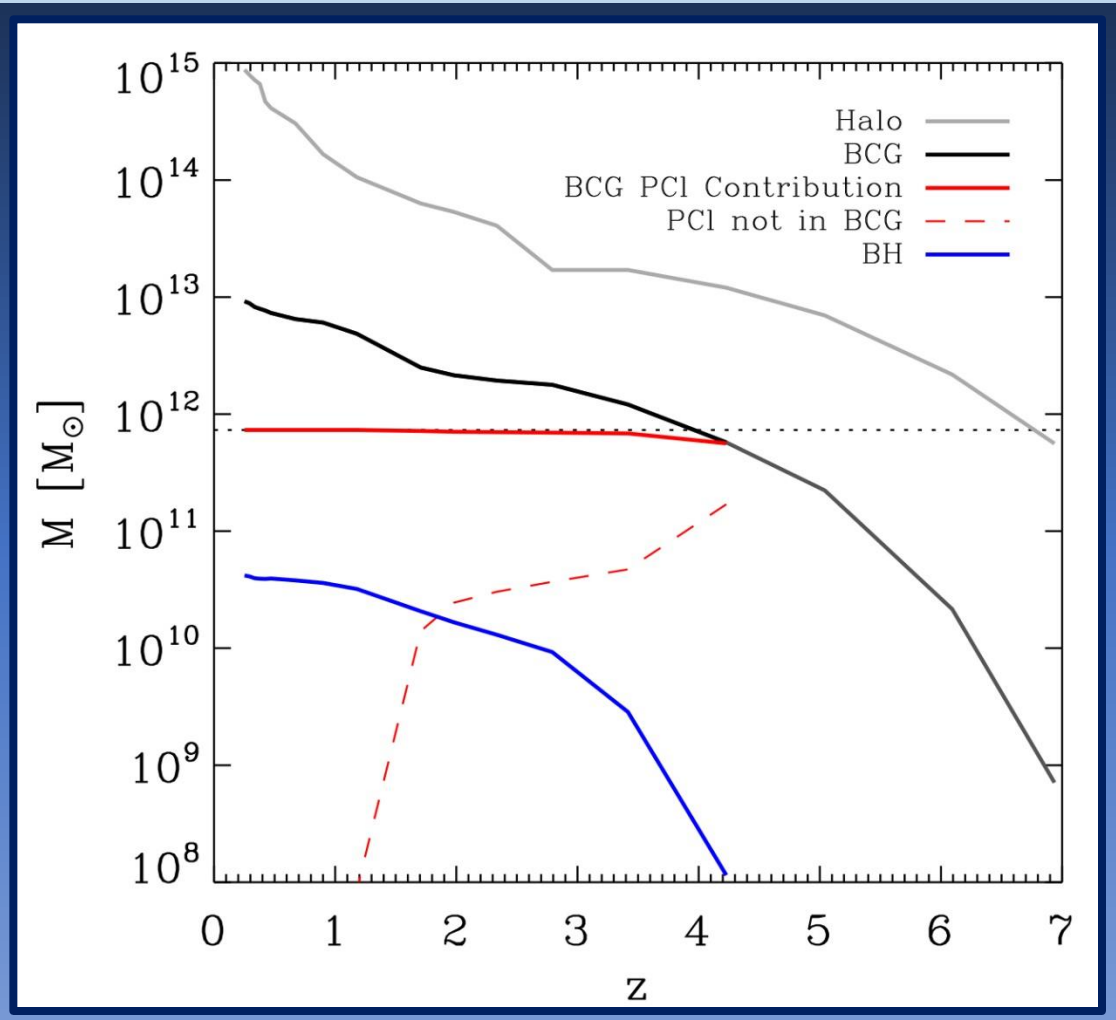
Protocluster in Magneticum: BCG Assembly





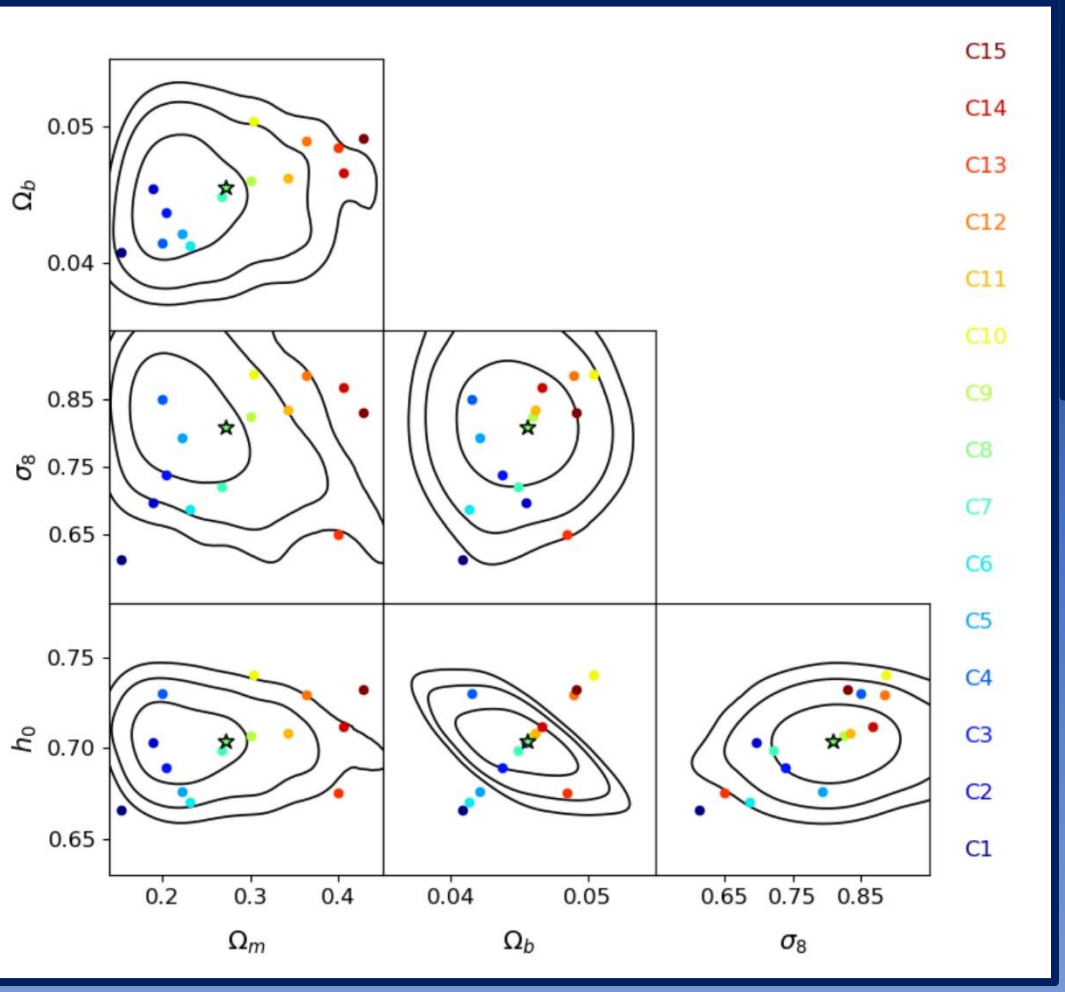
Protocluster in Magneticum: BCG Assembly





See also Rennehan et al., 2019 for BCG formation in Simulations and his Poster

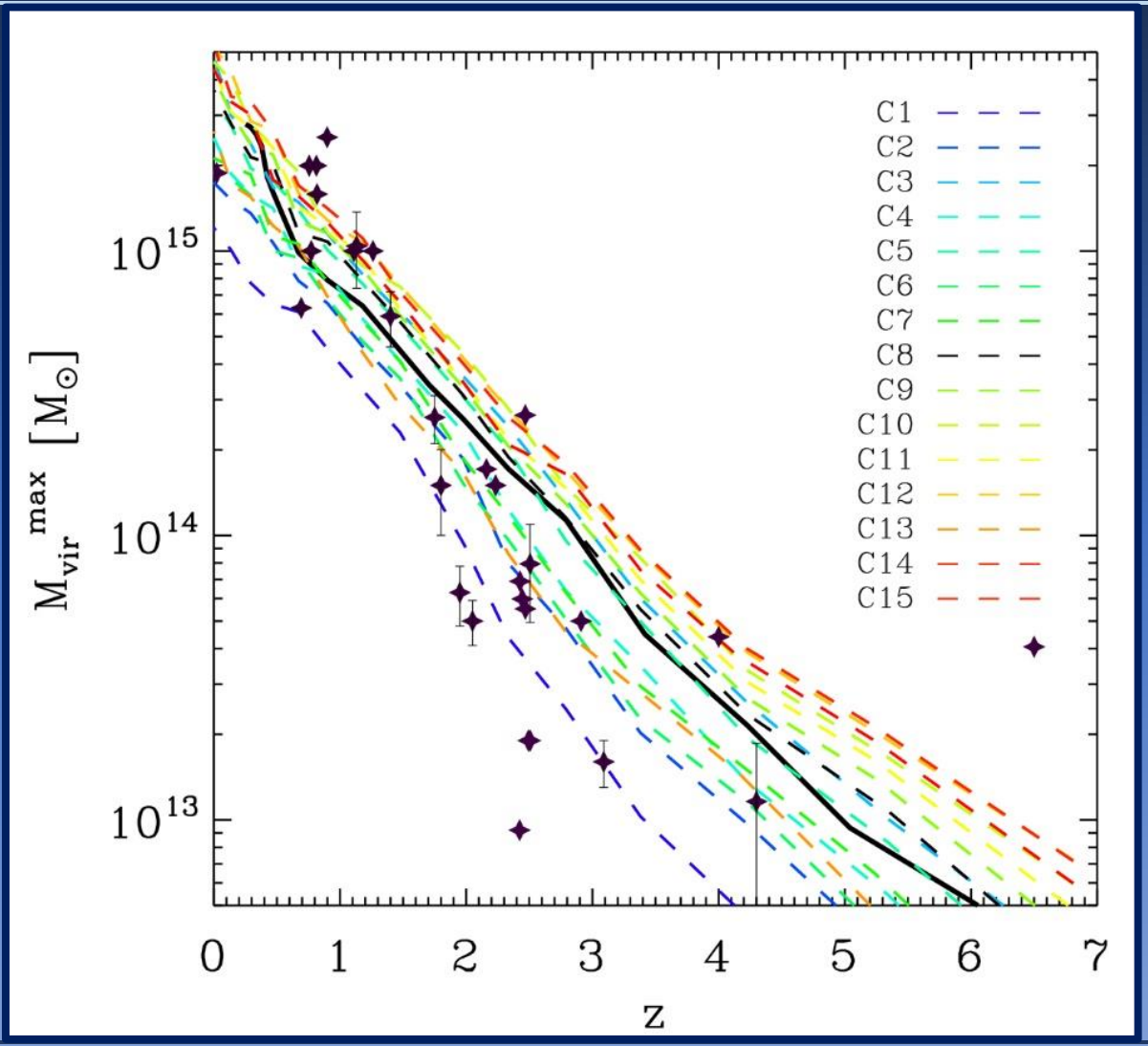
Protocluster in Magneticum: Cosmology Test



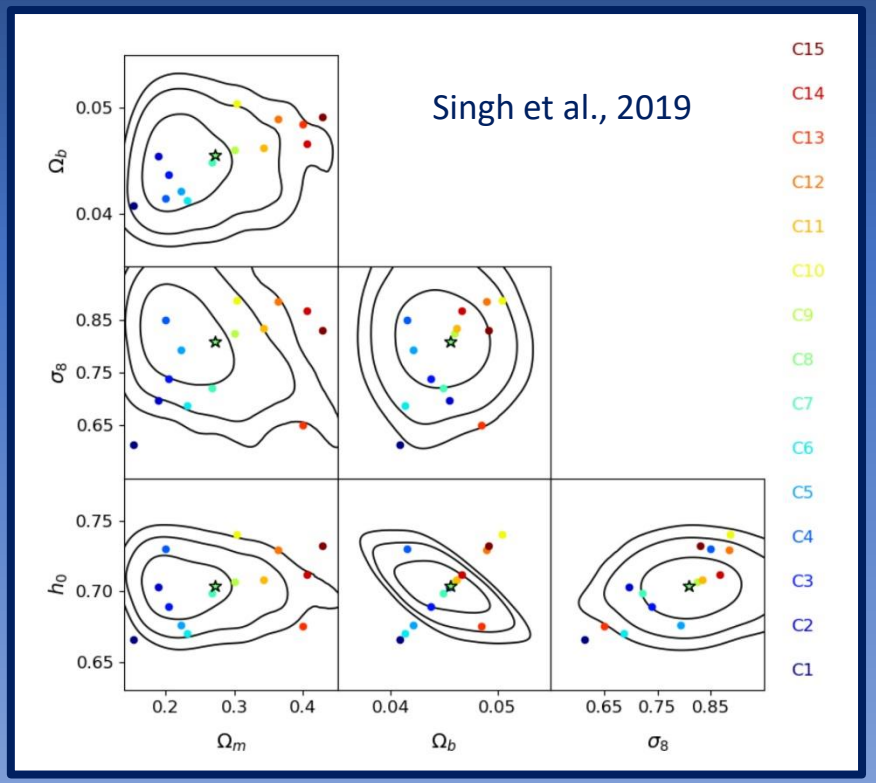
	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15
Ω_m	0.153	0.189	0.200	0.204	0.222	0.232	0.268	0.272	0.301	0.304	0.342	0.363	0.400	0.406	0.428
Ω_b	0.0408	0.0455	0.0415	0.0437	0.0421	0.413	0.0449	0.0456	0.0460	0.0504	0.0462	0.0490	0.0485	0.0466	0.0492
σ_8	0.614	0.697	0.850	0.739	0.793	0.687	0.721	0.809	0.824	0.886	0.834	0.884	0.650	0.867	0.830
h_0	0.666	0.703	0.730	0.689	0.676	0.670	0.699	0.704	0.707	0.740	0.708	0.729	0.675	0.712	0.732
f_b	0.267	0.241	0.208	0.214	0.190	0.178	0.168	0.168	0.153	0.166	0.135	0.135	0.121	0.115	0.115

Singh et al., 2019. The star marks the WMAP-7 cosmology used for the standard Magneticum Pathfinder runs

Protocluster in Magneticum: Cosmology Test



σ_8 most important for slope of M_{vir}-z relation.



Summary & Conclusions

- Massive protoclusters like SPT2349-56 can be found in Magneticum at $z \sim 4.3$.
- Number of member galaxies, phase-space properties, spatial distributions, and cold gas properties are well captured by the simulation.
- Star formation rates are too low, but gas mass and star formation main sequence are well captured even at high redshifts.

  → Star formation more bursty than included in our model!
- Our protoclusters at $z = 4.3$ evolve into halo at $z = 0$ covering a large range of masses.

  → Not all of them are massive clusters at z=0!
- Neither mass nor star formation at z=4.3 are a good measure of what to become, but the number of galaxies is – cosmic web tracing!
- BCG core assembles quickly from these protocluster-structures (about 1Gyr)
- Can be used to test cosmology

www.magneticum.org