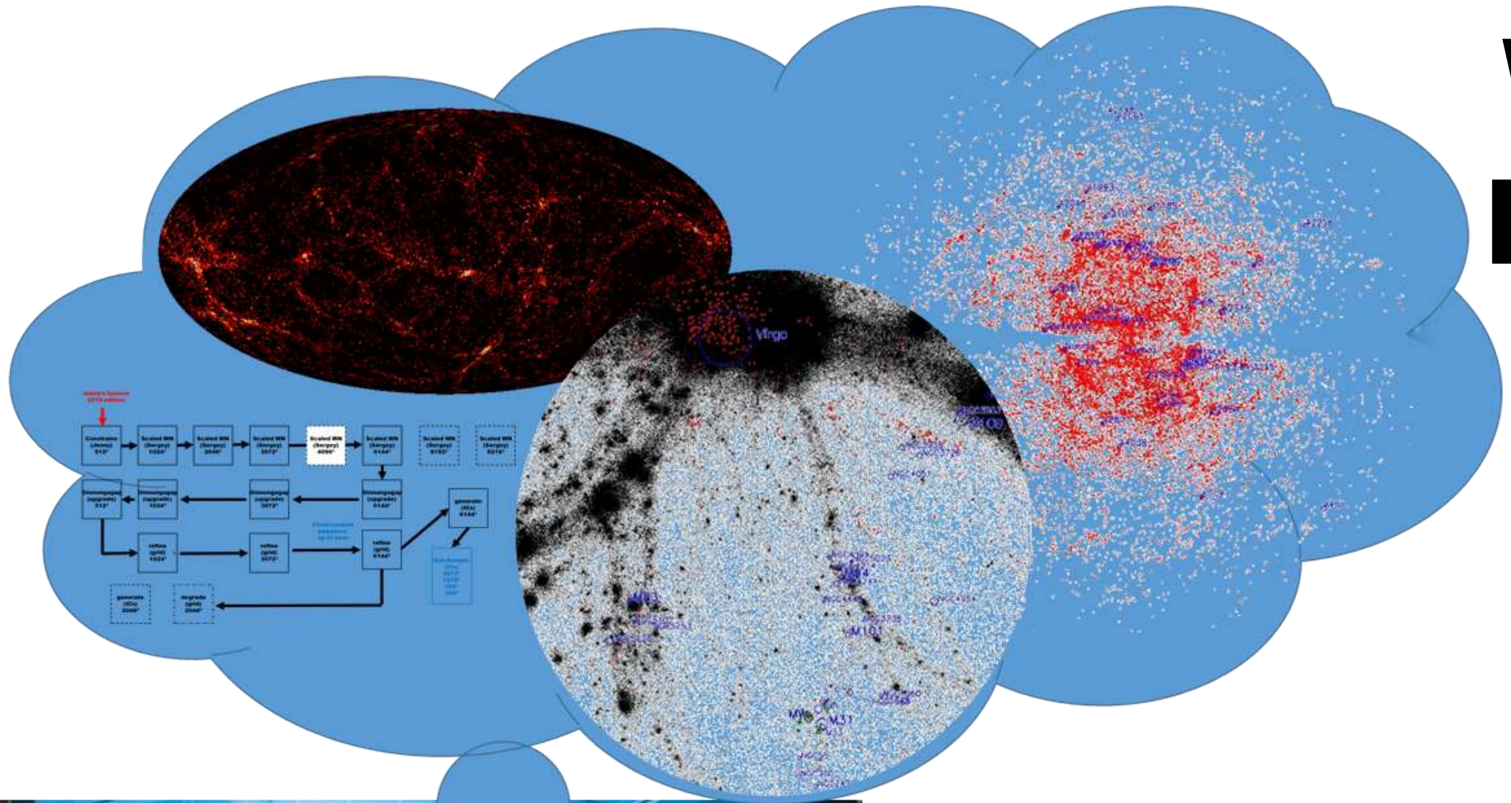
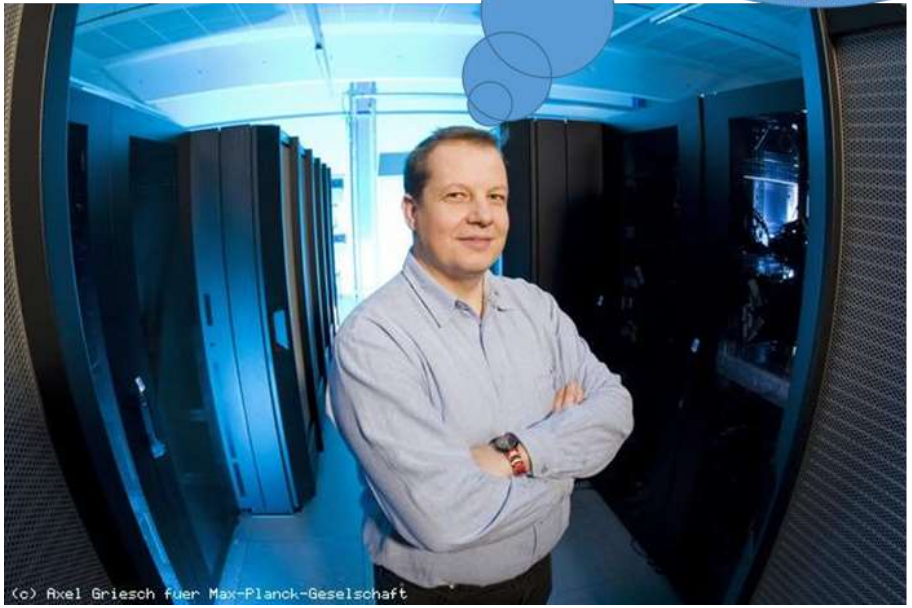


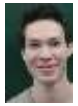
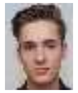
What does the Local Universe tell us about IGMF?

Klaus Dolag*
USM/LMU

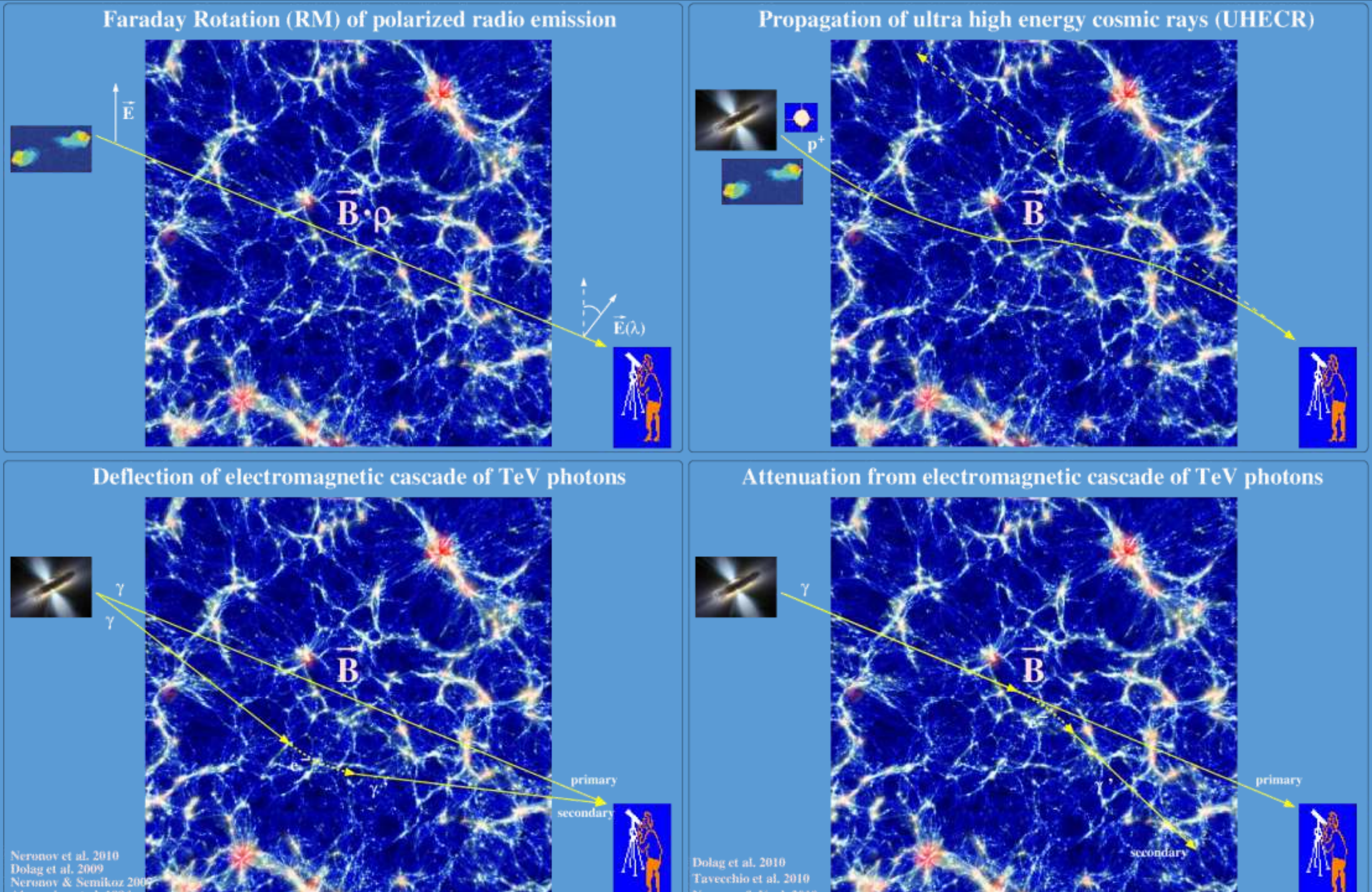
* 道楽



ACME SPACE TUM LMU ORIGINS Excellence Cluster erc European Research Council COMPLEX LOCALIZATION anr agence nationale de la recherche DFG Deutsche Forschungsgemeinschaft

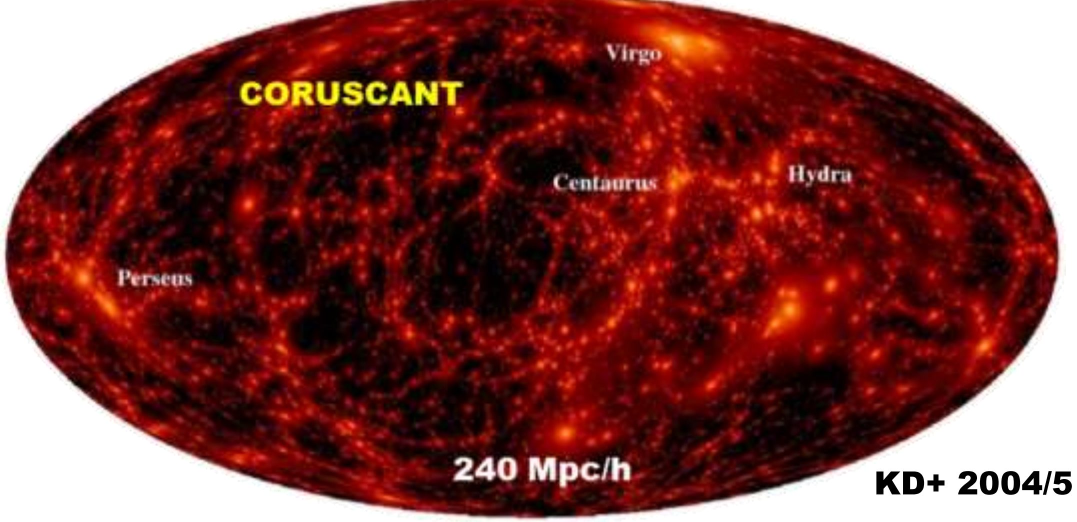
 M. Fischer
 E. Hernandez
 U. Steinwandel
 D. Karner
 T. Marin
 I. Khabibullin
 J. Stoiber
 F. Groth
 L. Böss
 B. Seidel

Motivation

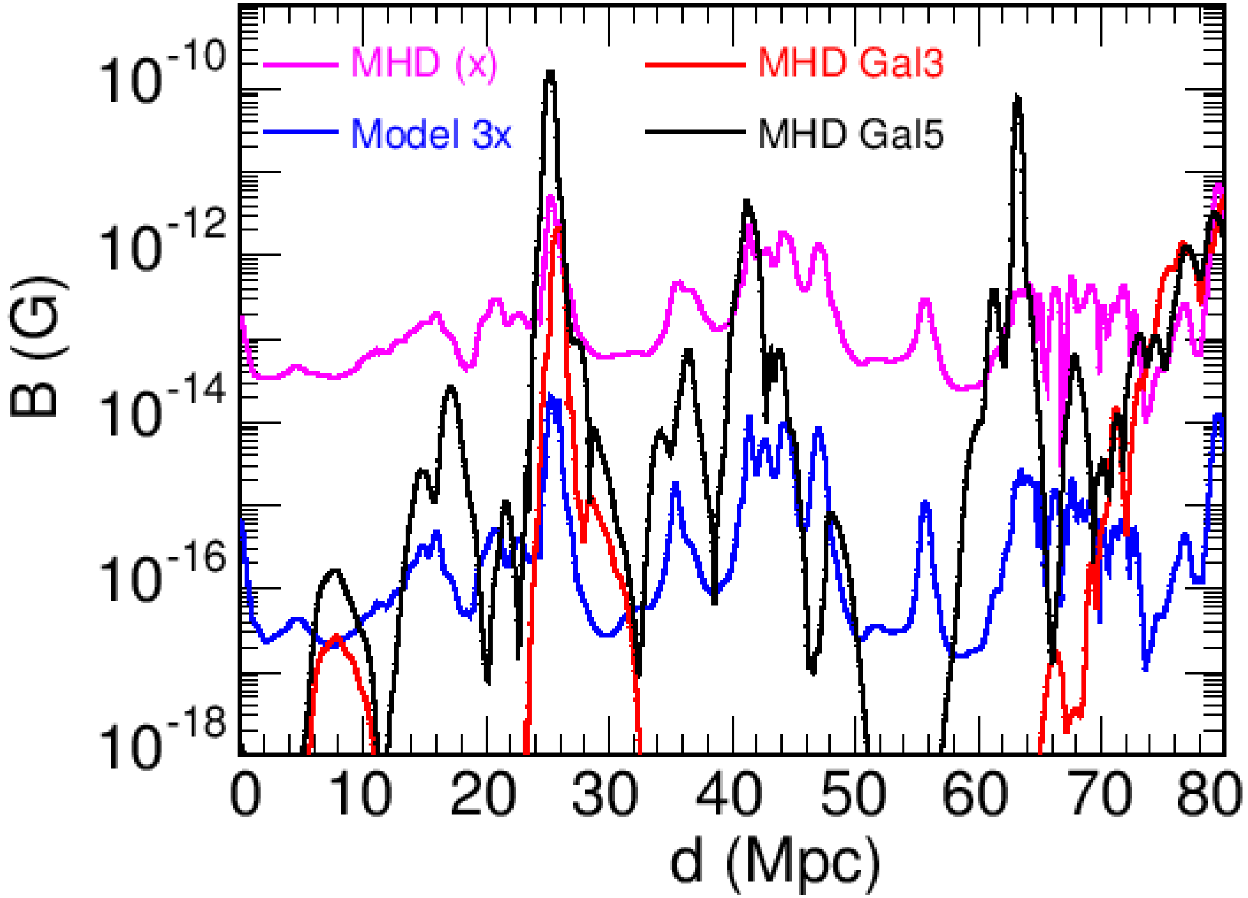


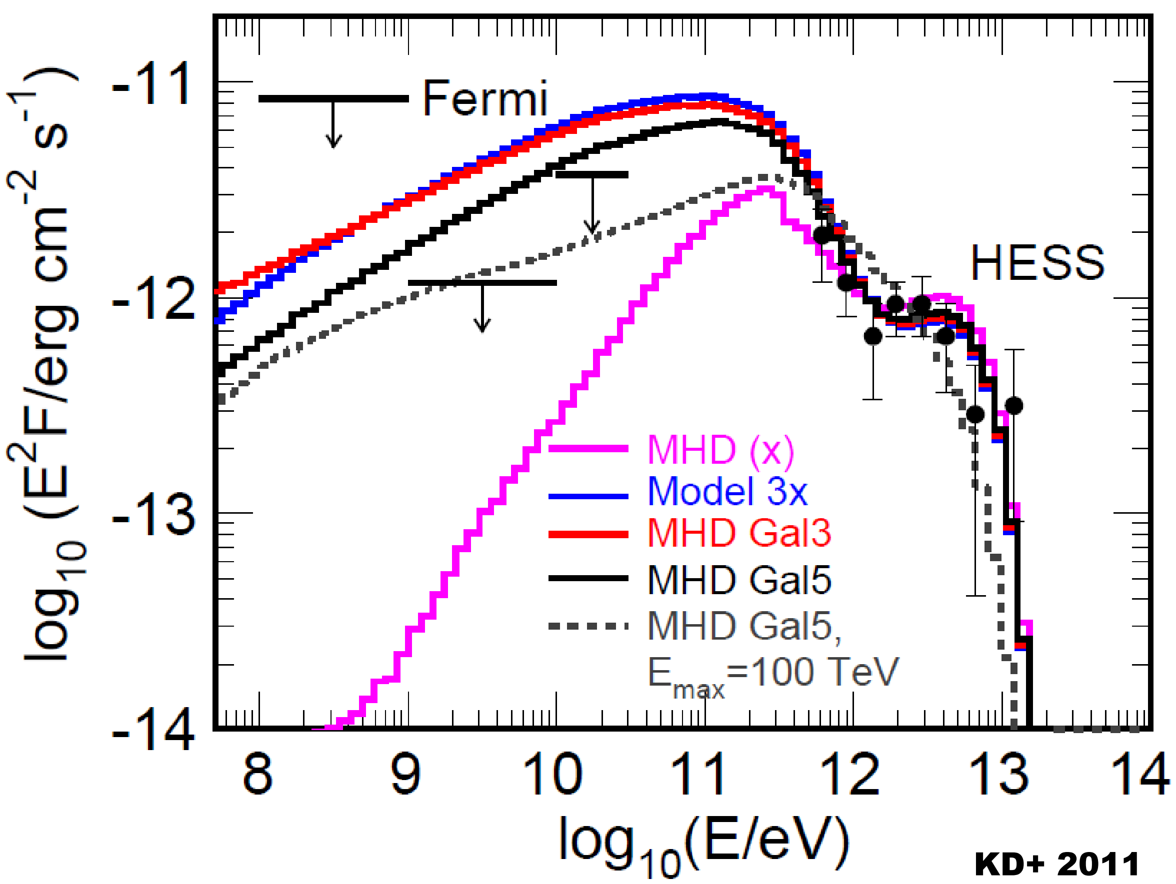
Faraday Rotation (RM) of polarized radio emission
E
B·ρ
E(λ)
Propagation of ultra high energy cosmic rays (UHECR)
p+
B
Deflection of electromagnetic cascade of TeV photons
γ
γ
B
e−
γ
primary
secondary
Neronov et al. 2010
Dolag et al. 2009
Neronov & Semikoz 2009
Attenuation from electromagnetic cascade of TeV photons
γ
B
e−
γ
primary
secondary
Dolag et al. 2010
Tavecchio et al. 2010

Magnetic field along the line of sight towards 1ES 0229+200 for different MHD simulations of the Local Universe (CORUSCANT) and the effect on the fluence contained inside the 95% confidence contour of the PSF of Fermi-LAT.



KD+ 2004/5

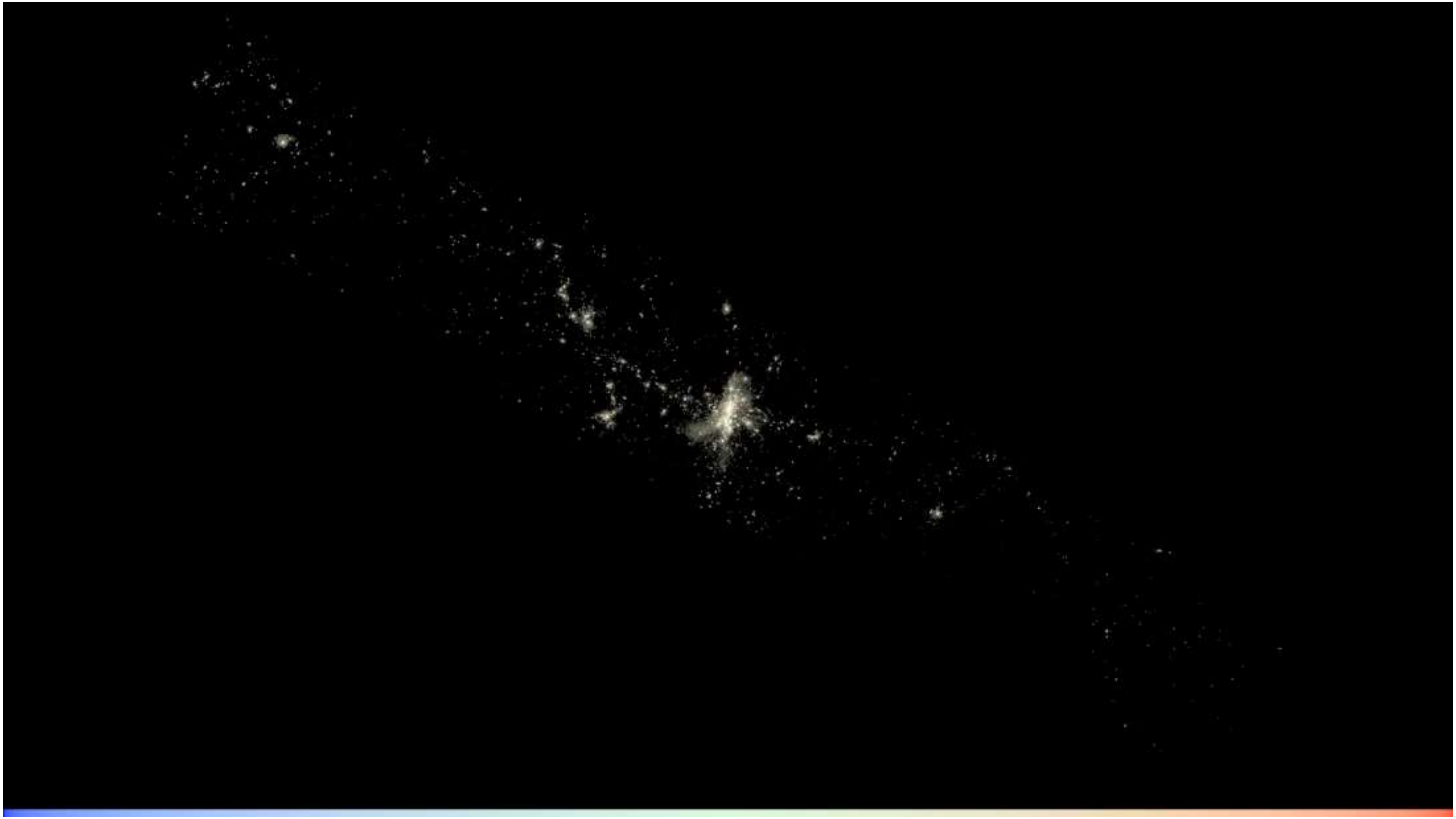




KD+ 2011

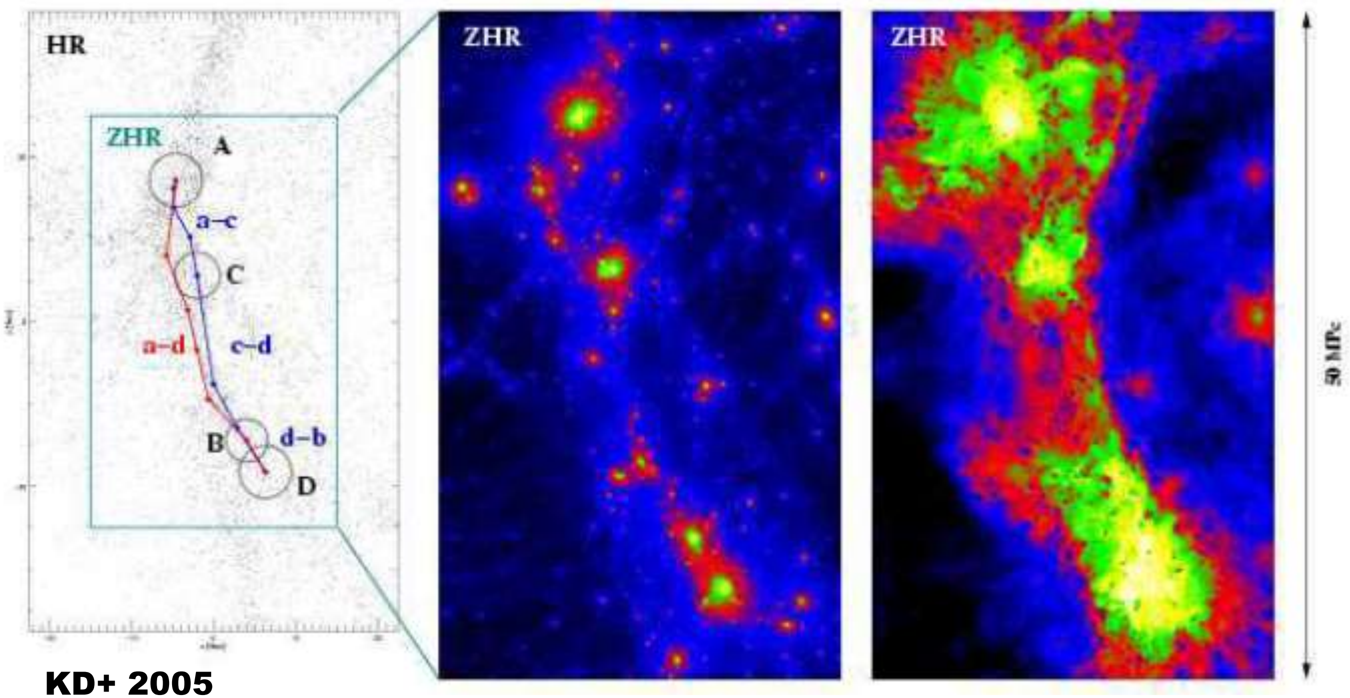
One example Filament

https://www.usm.uni-muenchen.de/~dolag/LEM/filament.avi

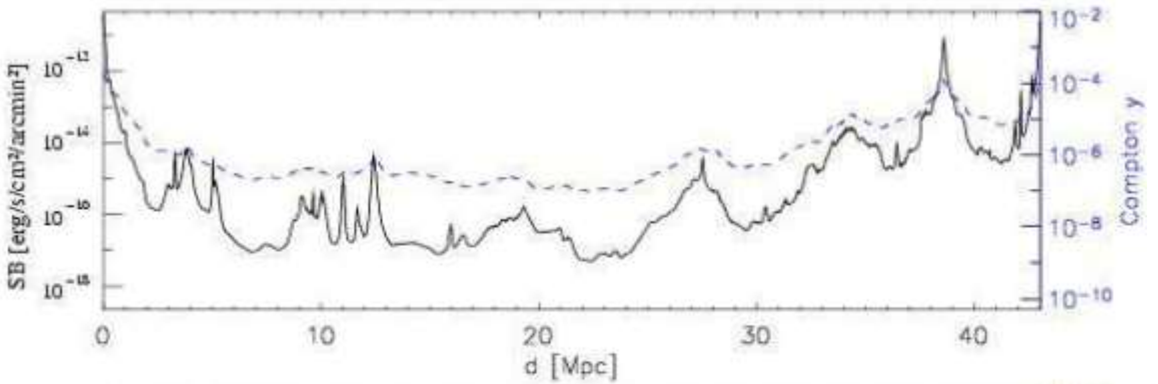


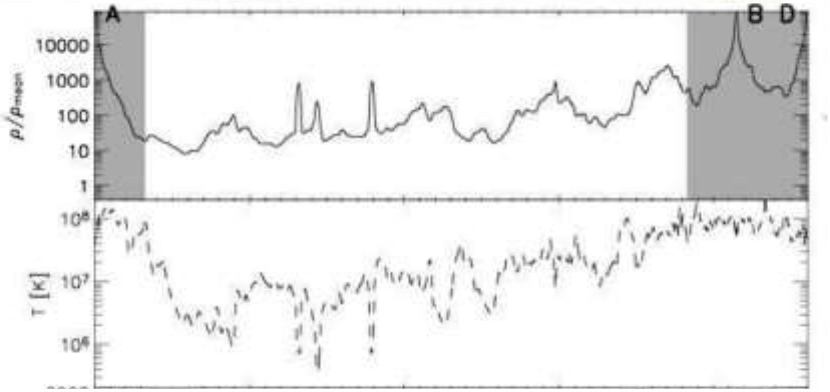
130 Mpc

Baryons in Filaments and it's location

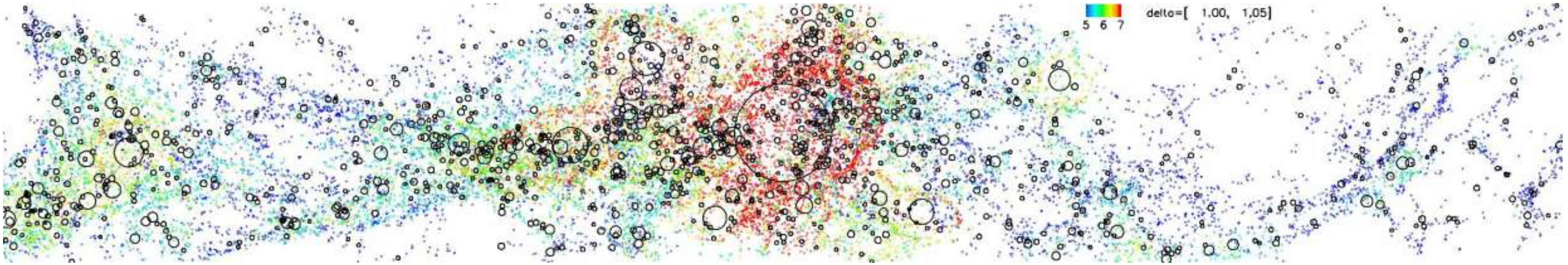


KD+ 2005





Outskirts vs Filaments



https://www.usm.uni-muenchen.de/~dolag/LEM/filament_composition.avi

About me

Klaus Dolag (USM/LMU)

PhD: MPA, *MHD Galaxy Cluster simulations*

PostDoc: MPA *(PLANCK satellite Group)*, Padova *(MC fellow)*, Bologna (*Guest Researcher*), MPA (*Researcher*), LMU (*Akademischer Rat*)

SPACE is a newly-funded EU Centre of Excellence focused on astrophysical and cosmological applications

- **Pushing OpenGadget3 for Exascale**
- **Preparing public release of OG3**

LOCALIZATION project funded by ANR PRCI gathers a team from Orsay and from Munich to produce the largest constrained simulations of our local Universe.

- **Large Box simulation / physics**
- **Full sky mock observations**
- **Galaxy Cluster zoomed simulations**

COMPLEX

- **MHD, origin of magnetic fields**
- **Treatment of viscosity**
- **Cosmic Ray treatment**
- **Radio emission**

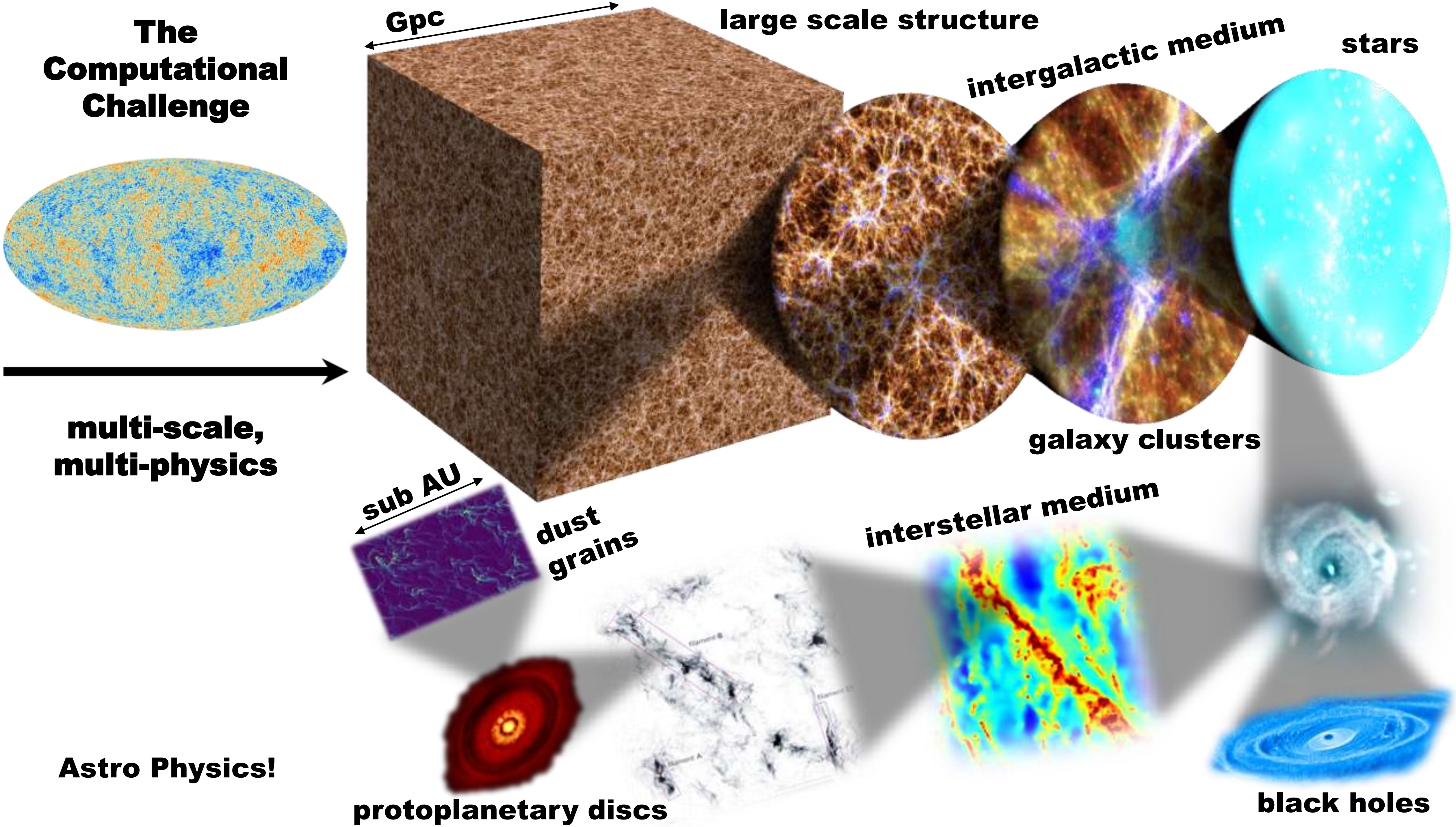
- **RU-C: Large Scale Structures**
- **RU-D: Galaxies, Stars, Planets**
- **CN-3: Dark Matter**
- **CN-5 Turbulence**

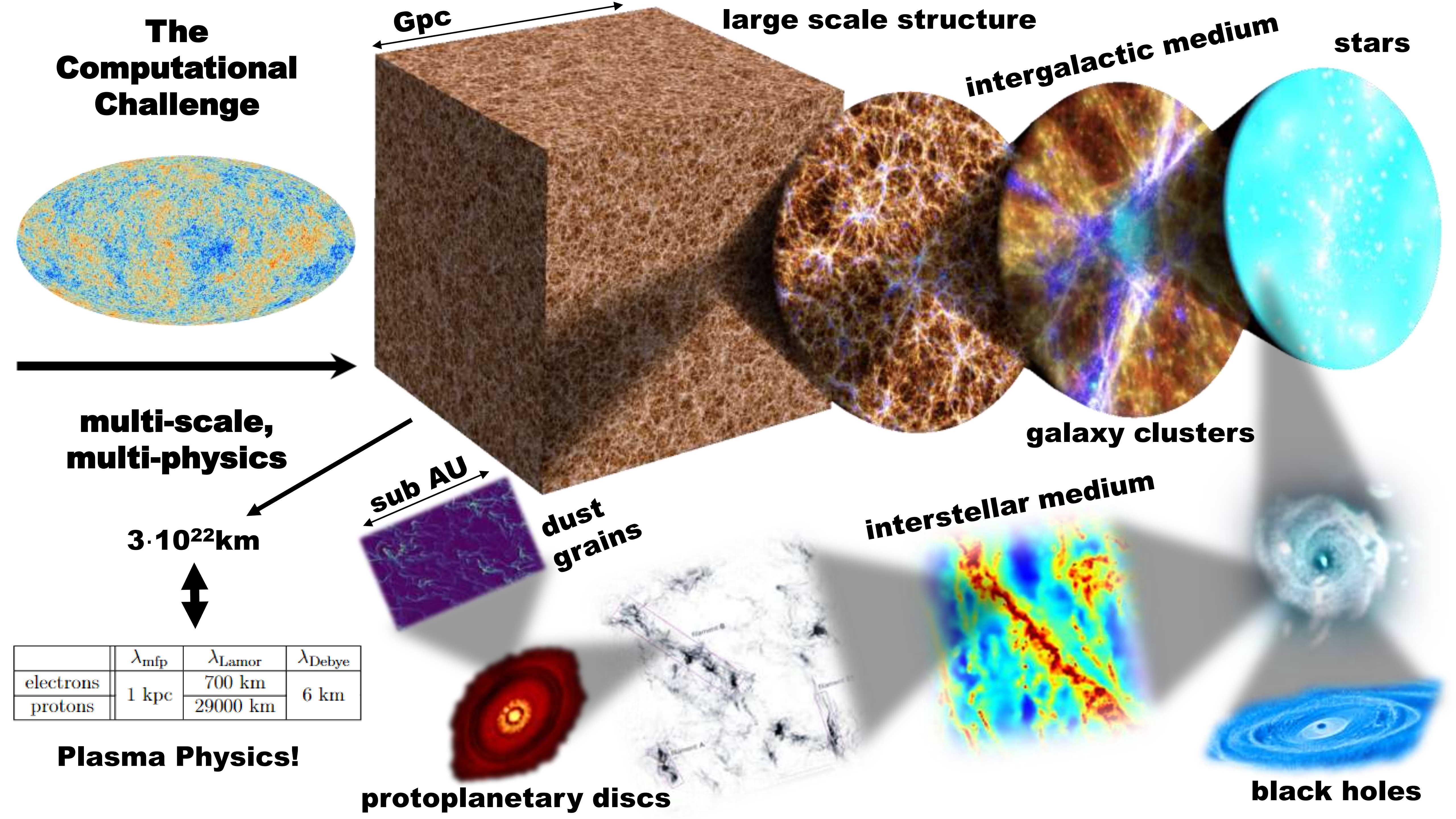
- **Interacting Dark Matter**
- **Axion Mini Cluster**
- **Axion-Quark Nuggets**

Astrophysics Center for Multimessenger studies in Europe

- **provide a hub to access models of the Local Universe**
- **improve predictions for Astrophysical, Multi-Messenger signals.**

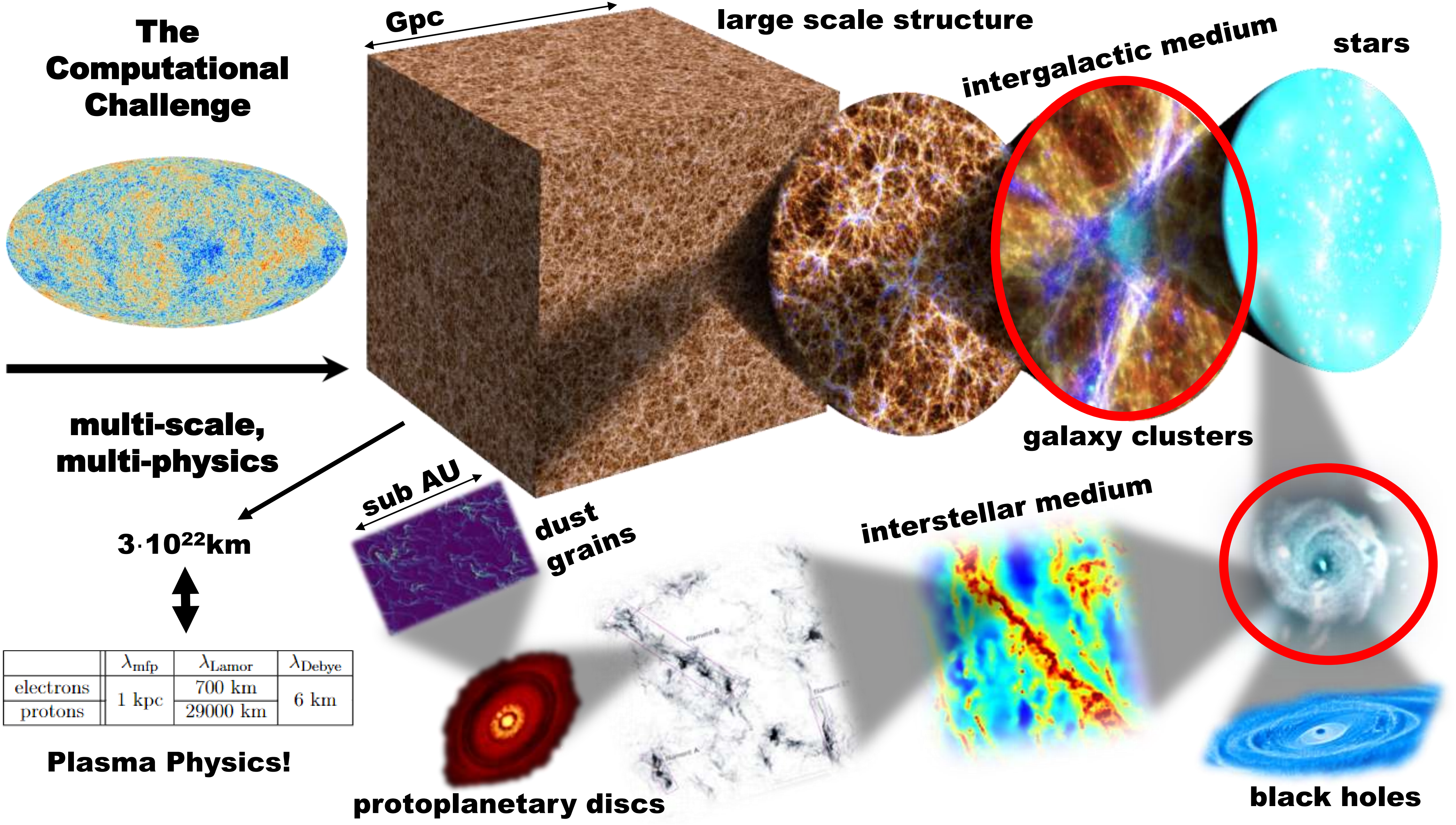
Intro I: The big picture


The Computational Challenge
multi-scale, multi-physics
Astro Physics!
Gpc
large scale structure
intergalactic medium
stars
galaxy clusters
sub AU
dust grains
interstellar medium
protoplanetary discs
black holes



	λ_{mfp}	λ_{Lamor}	λ_{Debye}
electrons	1 kpc	700 km	6 km
protons		29000 km	

The Computational Challenge



	λ_{mfp}	λ_{Lamor}	λ_{Debye}
electrons	1 kpc	700 km	6 km
protons		29000 km	

Plasma Physics!

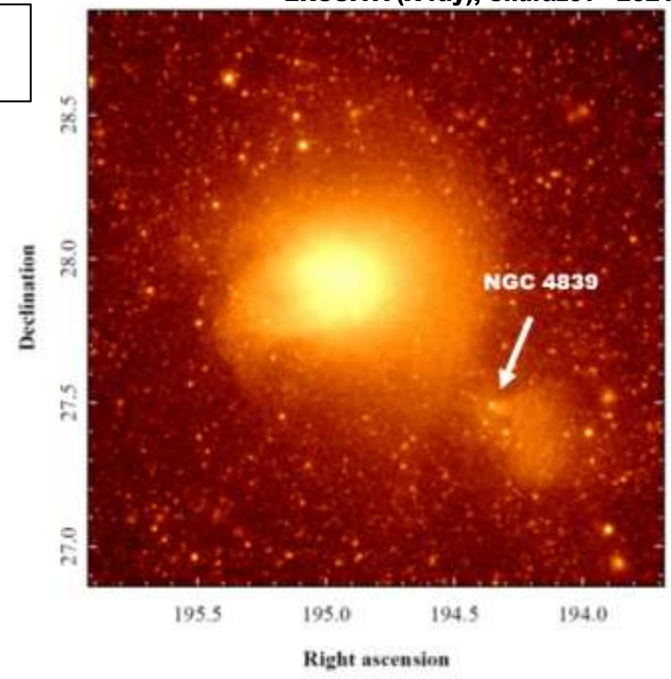
Intro II: The intra cluster medium (ICM)

ICM is the hot Atmosphere of Massive Galaxies

- Measured in large details
  X-ray (temperature, velocities)
  SZ (pressure)

EROSITA (X-ray), Churazov+ 2021

Coma

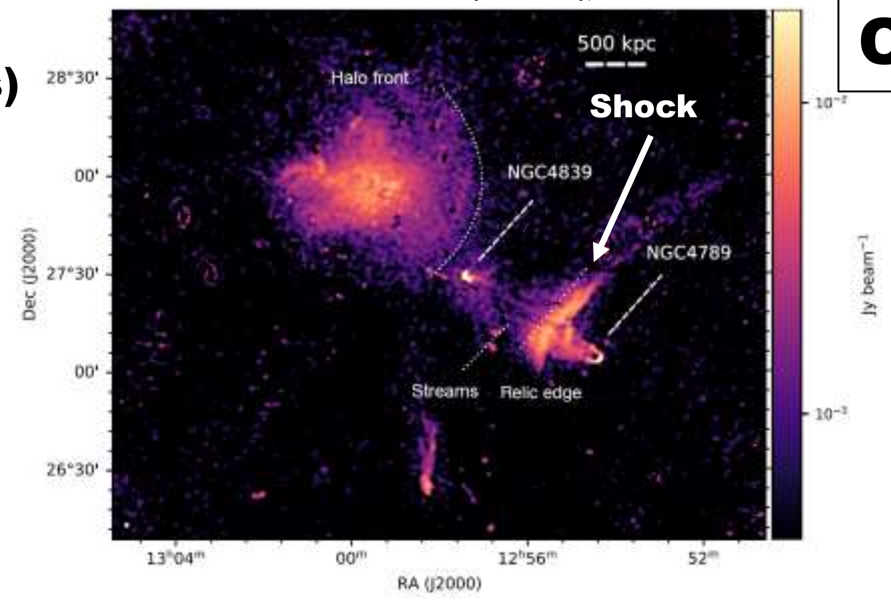


Density: 10^{2} to 10^{-3} part/cm³
Temperature: 10keV to 0.1keV

ICM is the hot Atmosphere of Massive Galaxies

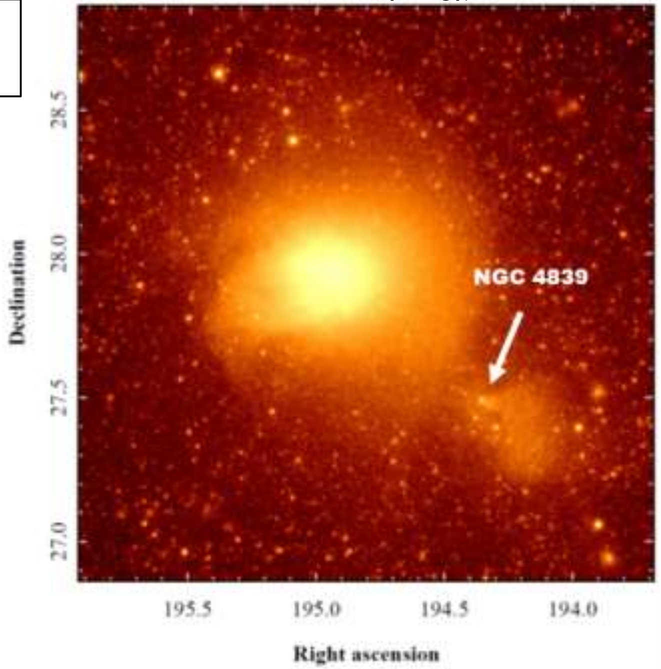
- ❑ **Measured in large details**
  X-ray (temperature, velocities)
  SZ (pressure)
- ❑ **Non-thermal components give additional insights (magnetic fields, CRs)**

LOFAR (144 MHz), Bonafede+ 2020

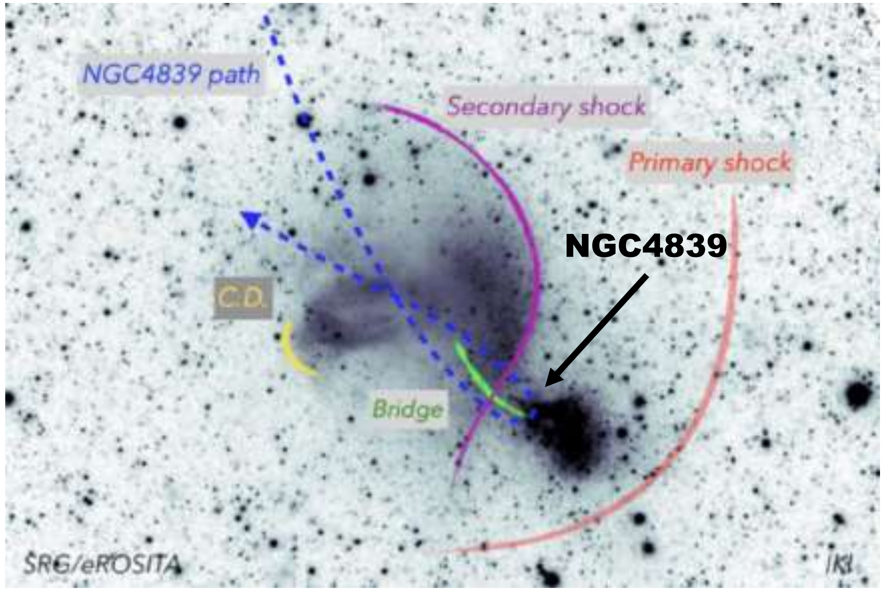


Coma

EROSITA (X-ray), Churazov+ 2021



Magnetic field: μG to nG
CR electrons: GeV



ICM is the hot Atmosphere of Massive Galaxies

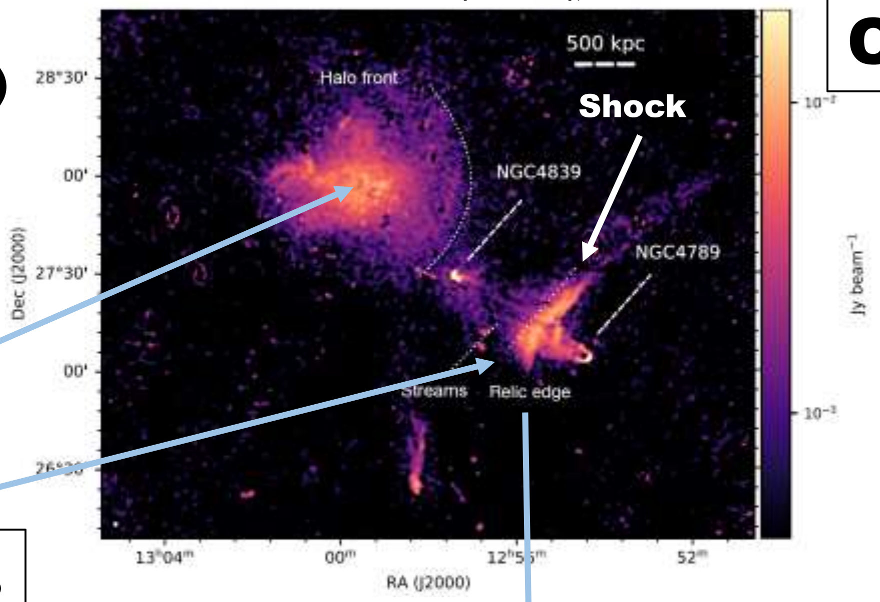
- ❑ Measured in large details
  X-ray (temperature, velocities)
  SZ (pressure)
- ❑ Non-thermal components give additional insights (magnetic fields, CRs)

Turbulence

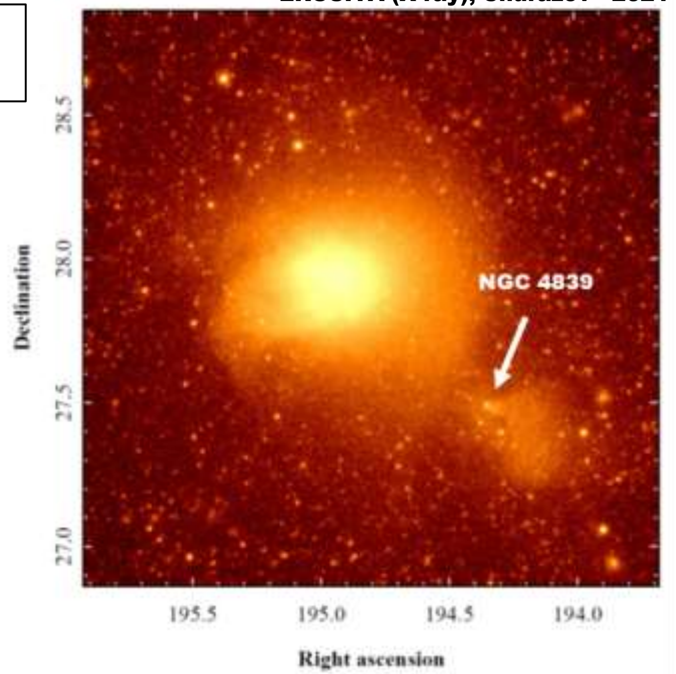
Shocks

Coma

LOFAR (144 MHz), Bonafede+ 2020



EROSITA (X-ray), Churazov+ 2021



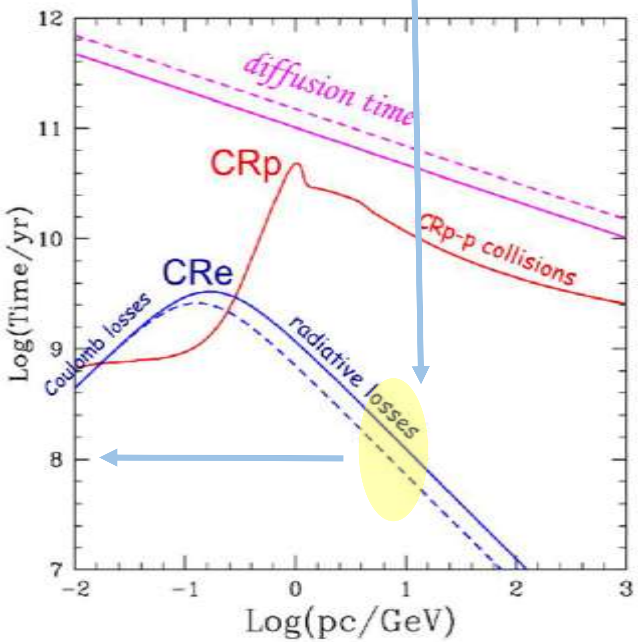
Short cooling time of CRe:

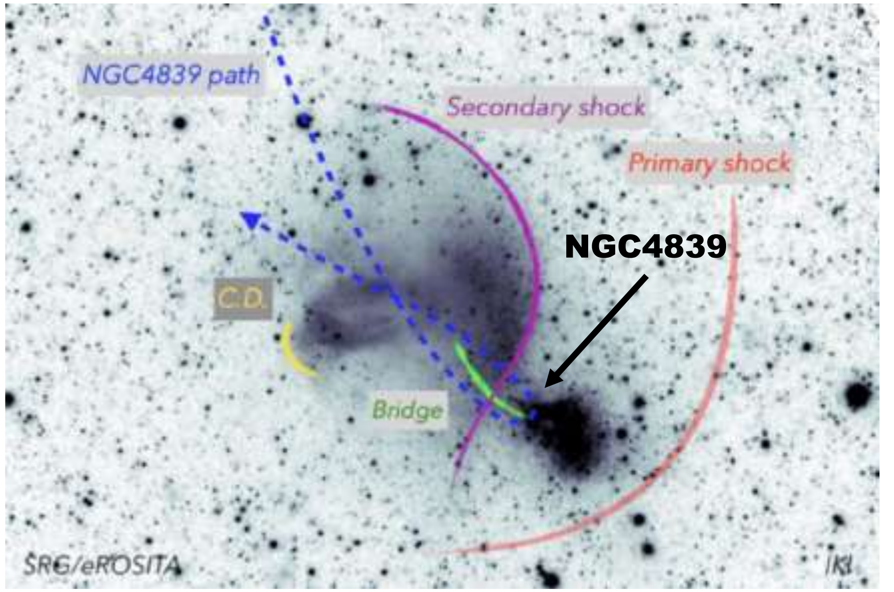
- ❑ test shocks on 10th of kpc
- ❑ test turbulence (re-acceleration)

Long cooling time of CRp:

- ❑ can be dynamically important

Both couple to B-Field





Simulations I: Galaxy Cluster, MHD and CRs

Cosmic Rays: The need for a a Fokker-Planck solver!

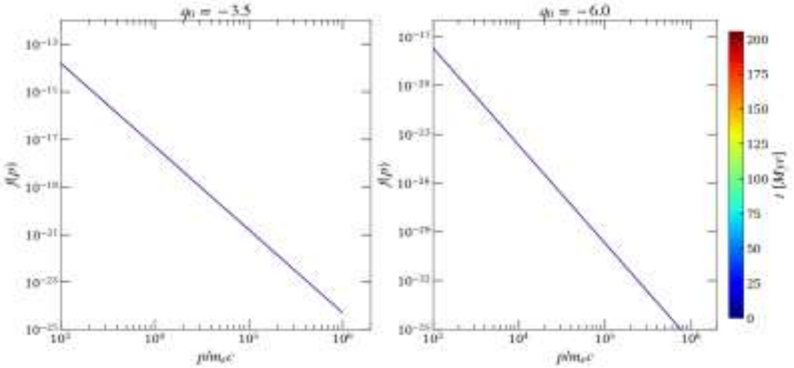
L. Böss

$$\frac{\partial f}{\partial t} + \underbrace{\mathbf{u}\cdot\nabla f}_{\text{spatial convection}} - \underbrace{\nabla\left(\boldsymbol{\kappa}\nabla f\right)}_{\text{spatial diffusion}} = \underbrace{\frac{1}{3}\left(\nabla\cdot\mathbf{u}\right)p\frac{\partial f}{\partial p}}_{\text{momentum convection}} + \underbrace{\frac{1}{p^2}\frac{\partial}{\partial p}\left(p^2\left[b_\ell f + D_p\frac{\partial f}{\partial p}\right]\right)}_{\substack{\text{momentum diffusion}\\ +\ \text{continuous losses}}} - \underbrace{\frac{f(p,\mathbf{x},t)}{t_c(p,\mathbf{x})}}_{\text{catastrophic losses}} + \underbrace{j(p,\mathbf{x})}_{\text{source term}}$$

Turbulence

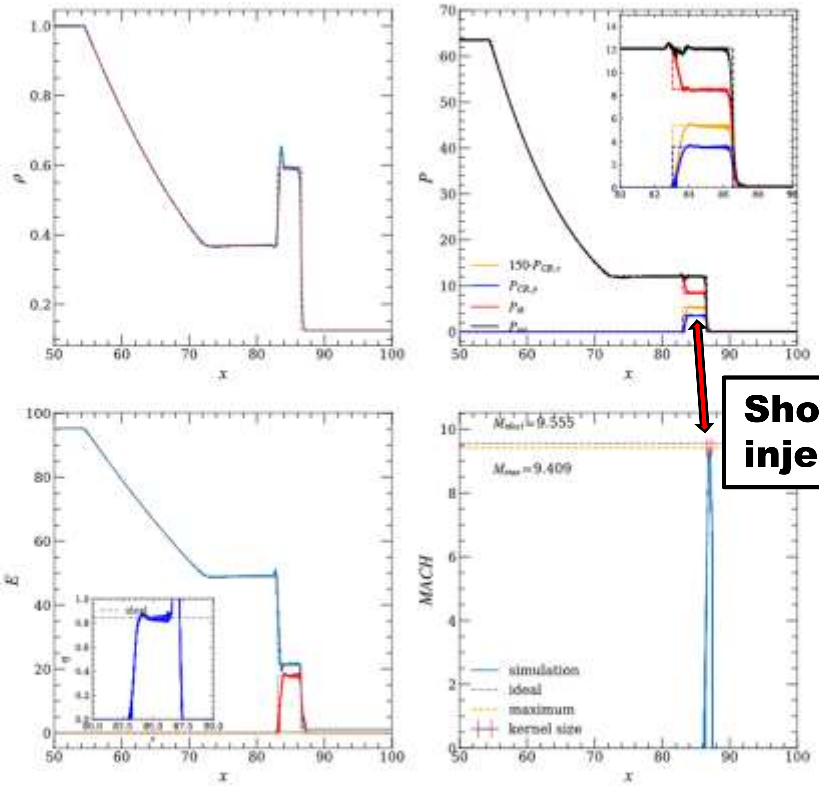
- **Shocks**
- SFR
- AGN

Cooling of CRe

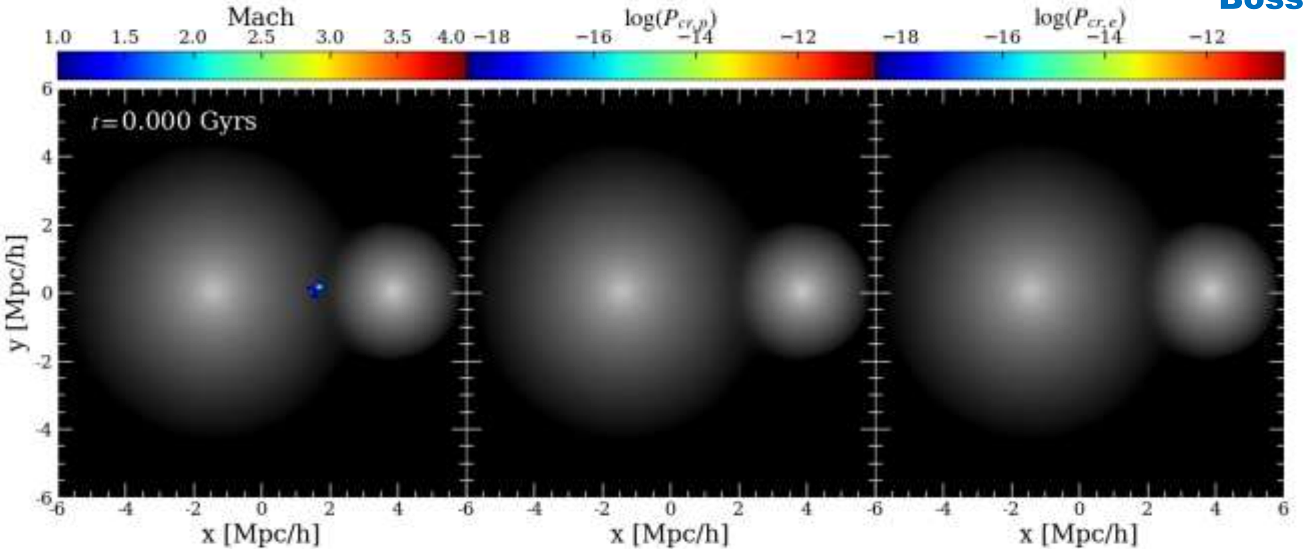


Every resolution element in a simulation has to additionally evolve a sampled distribution function of CR(e,p)!

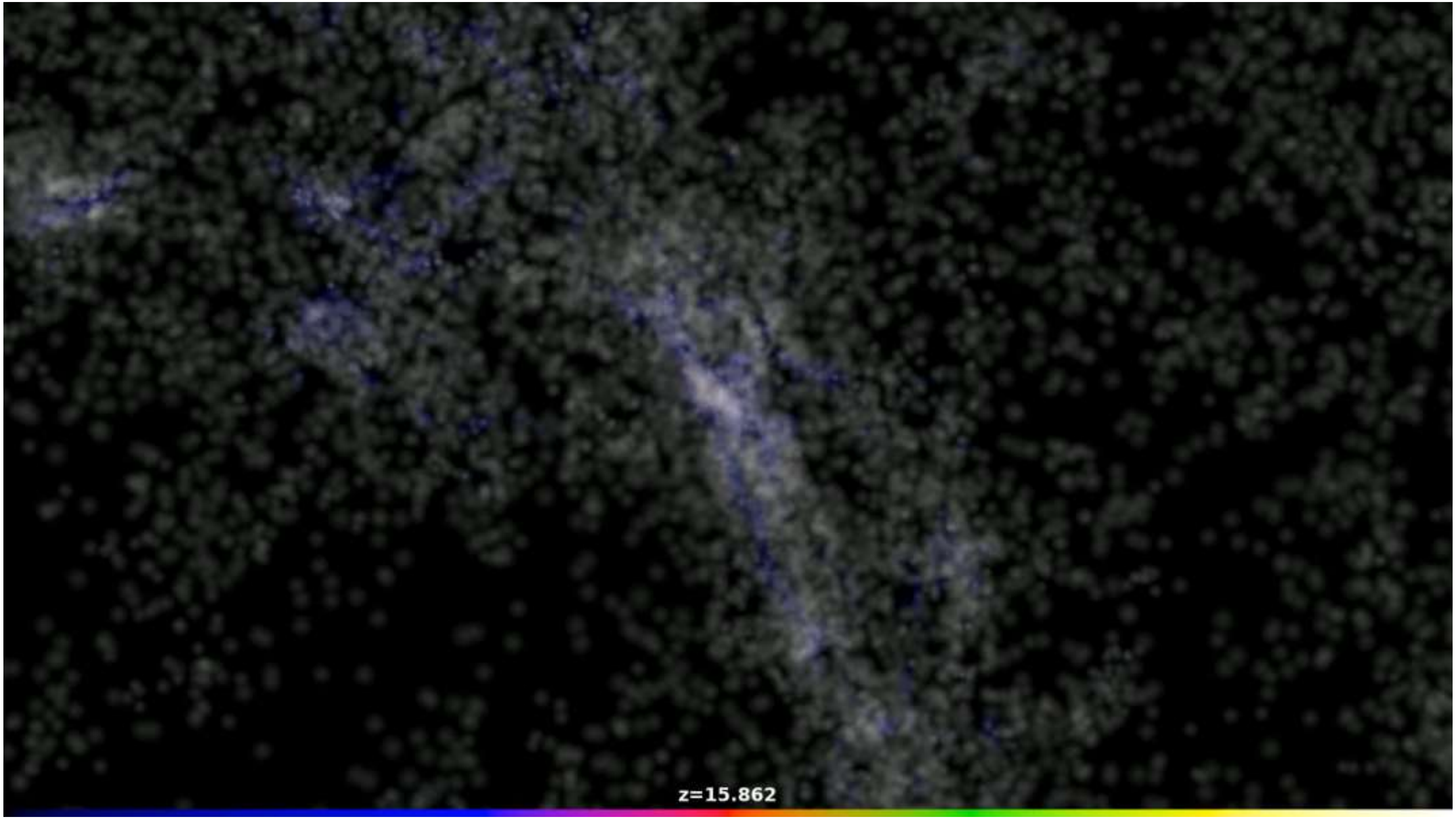
Böss et al. 2022



Shock injection



Simulating Galaxy Clusters and the ICM



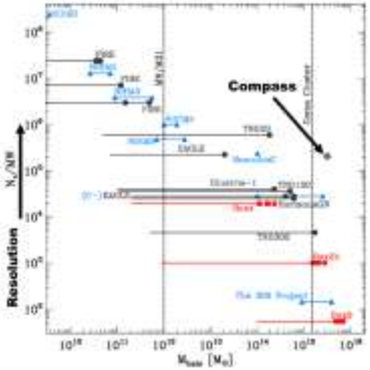
Mach number: 2 3 4 >5

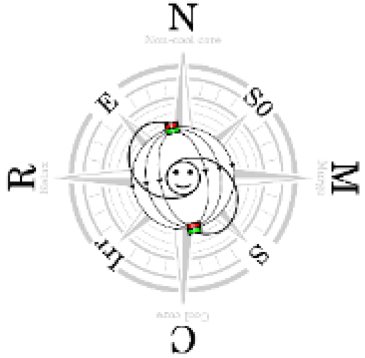
Galaxy Clusters:

M ~ $2x10^{15}M_{sol}$

almost 10^9 part in R_{vir}
~ 90.000 galaxies
~ 250.000 timesteps

$\varepsilon_{gas/stars}$ ~ 240 pc/h



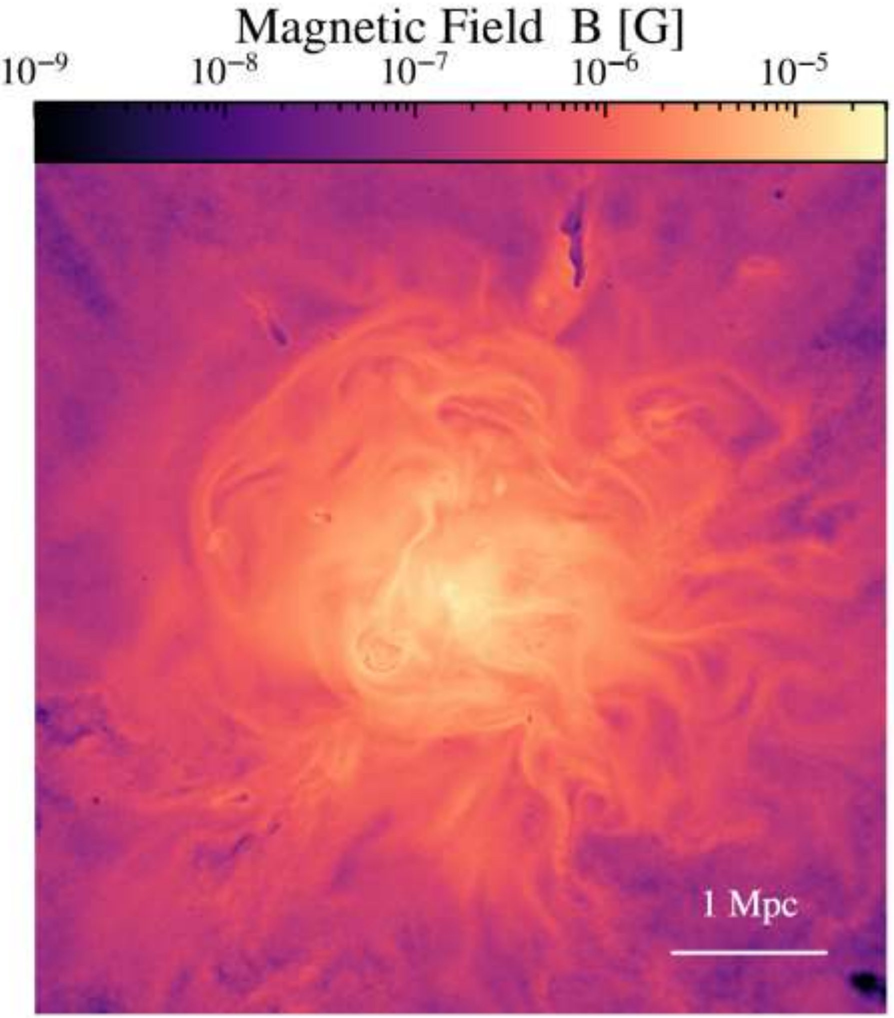


C·O·M·P·A·S·S

Simulations of turbulent dynamo in the ICM

U. Steinwandel

"Towards cosmological simulations of the magnetized intracluster medium with resolved Coulomb collision scale"



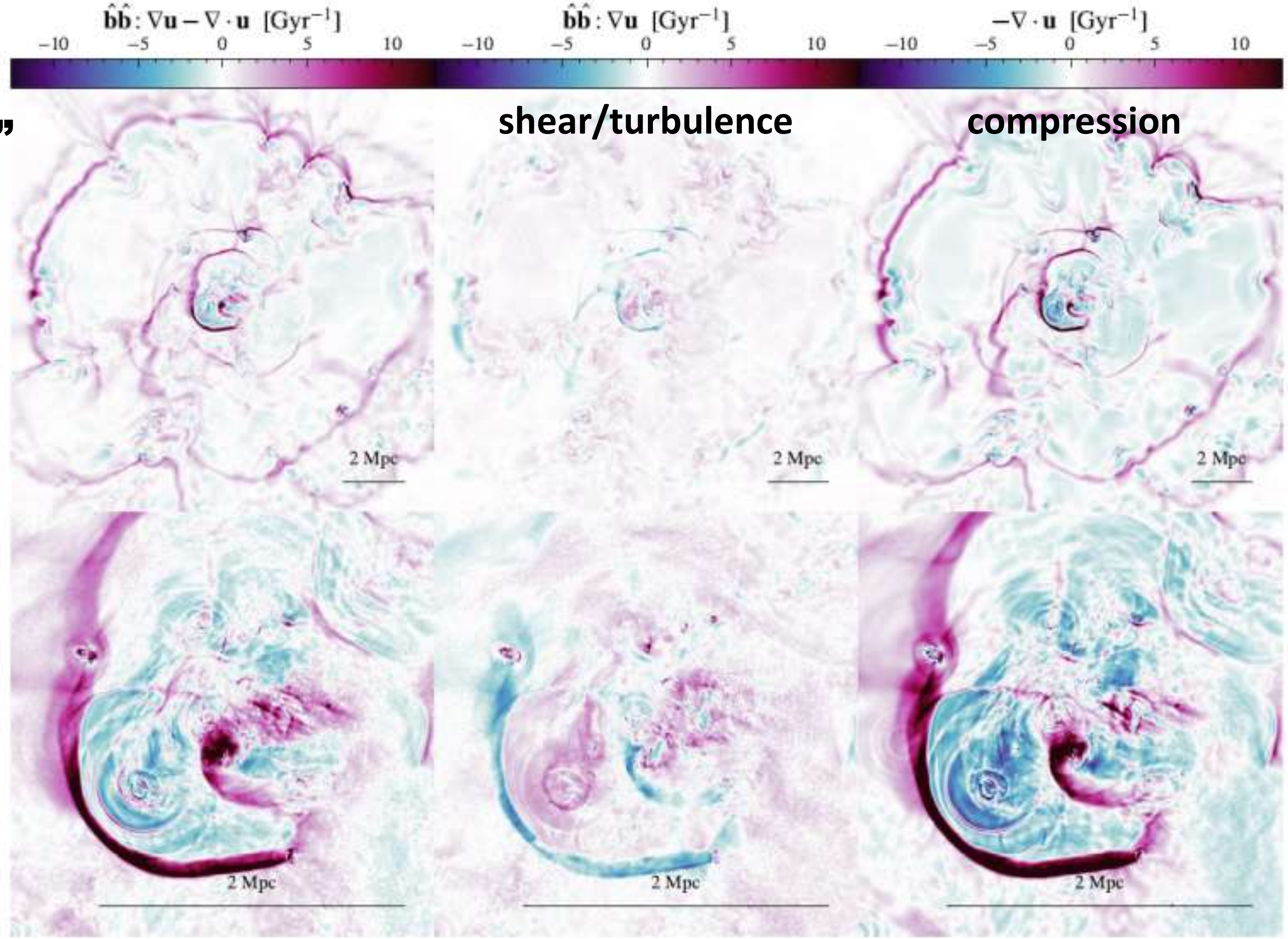
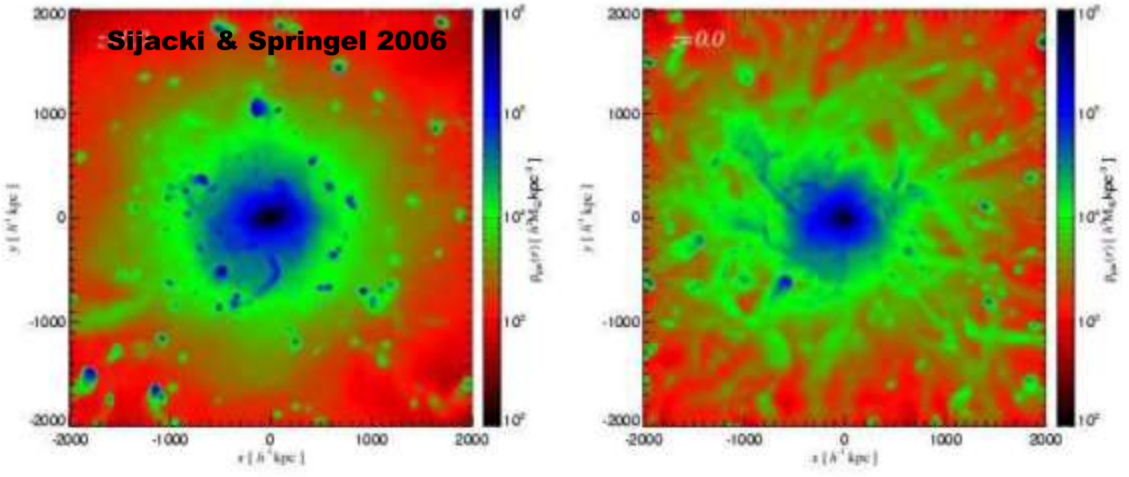


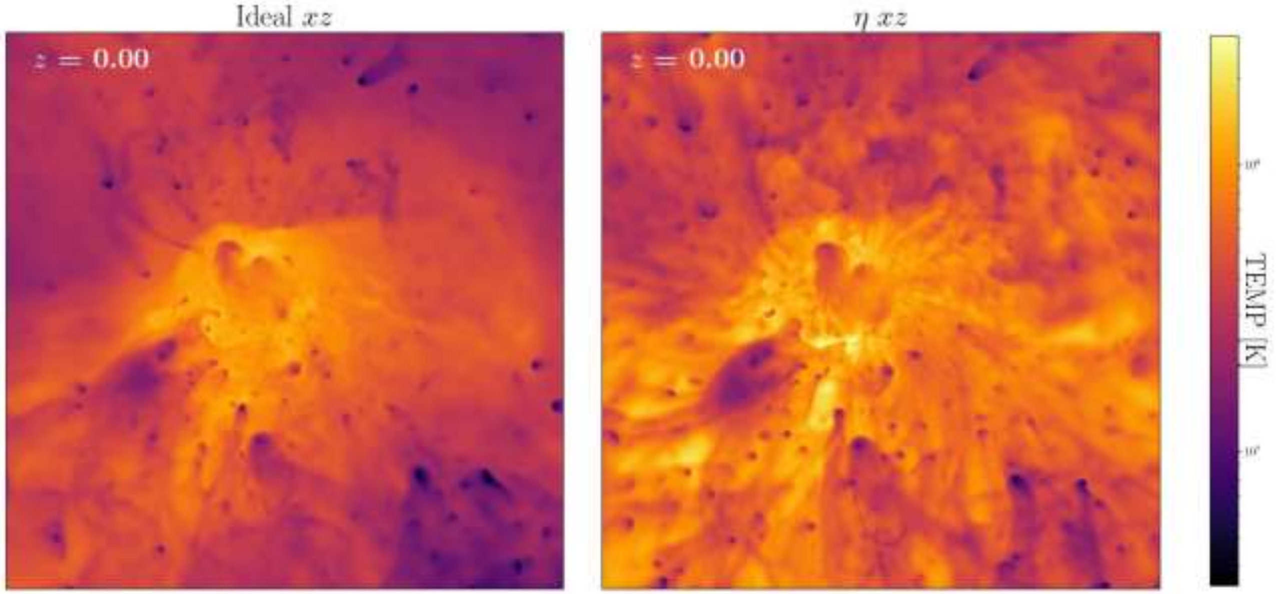
Figure 10. Total rate of change of the magnetic field (left), shearing/turbulent rate of change of the magnetic field (center), and compressive rate of change of the magnetic field (right). The top row shows the whole simulation domain, while the bottom panel is focusing on the field structure around a cold front that forms right at redshift zero through a sub-structure that is penetrating the cluster center.

Steinwandel+ 2023

Plasma Physics: Essential for mixing and multiphase nature of ICM

Effect of viscosity?





Marin-Gilabert+ 2022/24

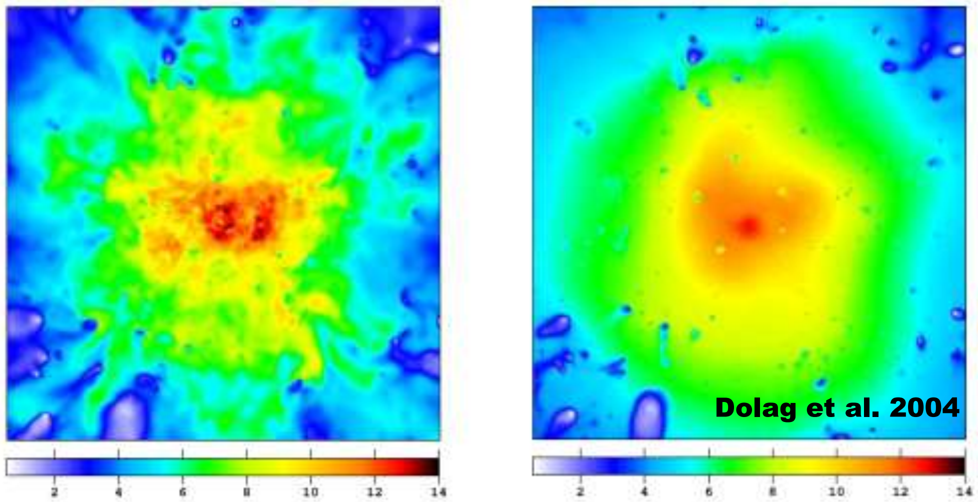
mach number — size of galaxies

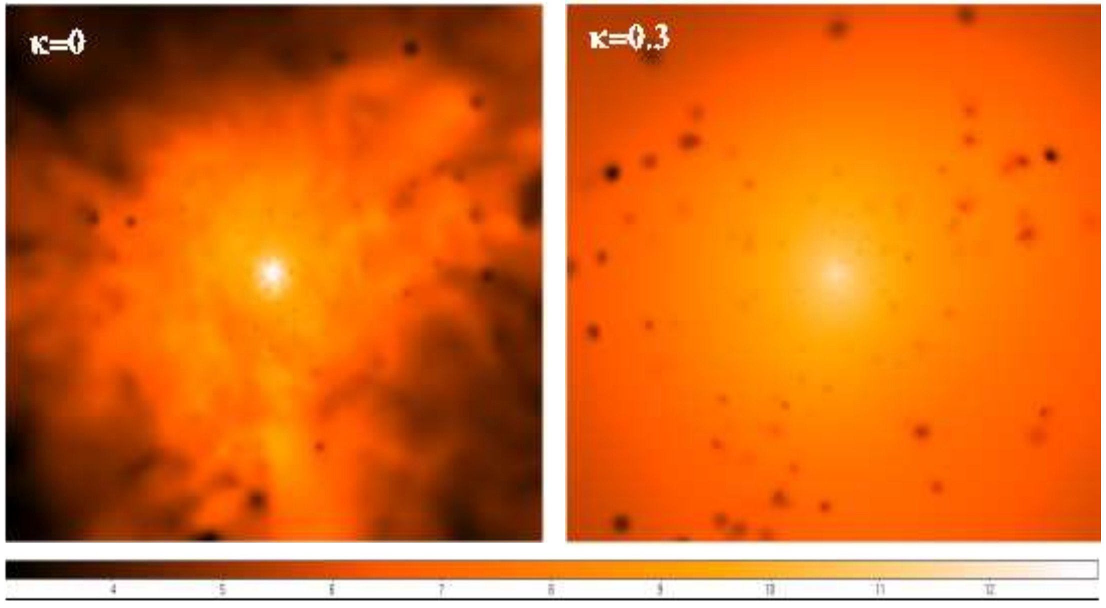
$Re \approx 3M\left(\frac{l}{\lambda_i}\right)$

$l \sim \lambda_i$!!!

ion mean free path: $\lambda_e = \lambda_i \approx 23\,\mathrm{kpc}\left(\frac{T_g}{10^8\,\mathrm{K}}\right)^2\left(\frac{n_e}{10^{-3}\,\mathrm{cm}^{-3}}\right)^{-1}$

Effect of thermal conduction?





Arth+ 2014

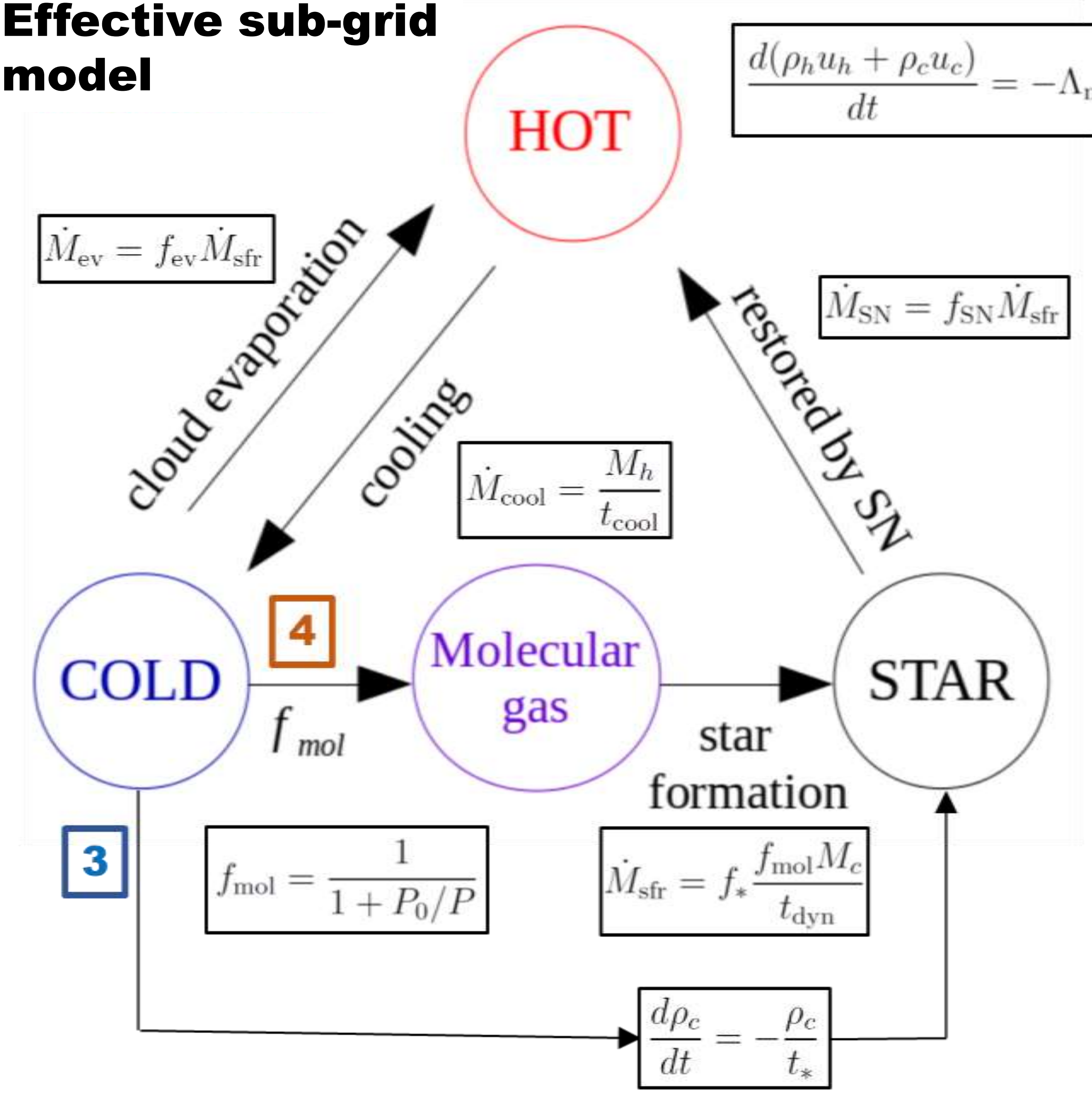
$$\kappa = 1.31 n_e \lambda_e k\left(\frac{kT_e}{m_e}\right)^{1/2} \approx 4.6\times10^{13}\left(\frac{T_e}{10^8\,\mathrm{K}}\right)^{5/2}\left(\frac{\ln\Lambda}{40}\right)^{-1} \mathrm{erg\,s^{-1}\,cm^{-1}\,K^{-1}}.$$

Simulations II: Galaxy Formation physics

Basics: Simulation of star-formation

Ω_{stars} ~ 0.002
Ω_{gas} ~ 0.038
Ω_{dm} ~ 0.267
Ω_{Λ} ~ 0.693

Effective sub-grid model



$$\frac{d(\rho_h u_h + \rho_c u_c)}{dt} = -\Lambda_{net}(\rho_h u_h) + \beta \frac{\rho_c}{t_*} u_{SN} - (1-\beta)\frac{\rho_c}{t_*} u_c$$

$$\dot{M}_* = \dot{M}_{sfr} - \dot{M}_{SN}$$
$$\dot{M}_c = \dot{M}_{cool} - \dot{M}_{sfr} - \dot{M}_{ev}$$
$$\dot{M}_h = -\dot{M}_{cool} + \dot{M}_{SN} + \dot{M}_{ev}$$

System of differential equations -> Solutions

Different Variants:

- **3 Phases**
- **4 Phases**
- **Equilibrium solution**
- **Dynamical solution**
- **Empirically motivated**
- **Theoretically motivated**

Extensions:

- **Stellar/Chemical Evolution**
- **Kinetic feedback**

Basics: Including Black Holes in Simulations

Sub-grid model for handling black holes in cosmological simulations:

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 (Steinborn 2015)
- ....

⇓

Merging
- Instant merging
- Based on velocity
- ....

⇒

Positioning:
- Pinning to min. Potential
- Free floating

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 (ρ); sound speed (c_s)

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

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 (f)

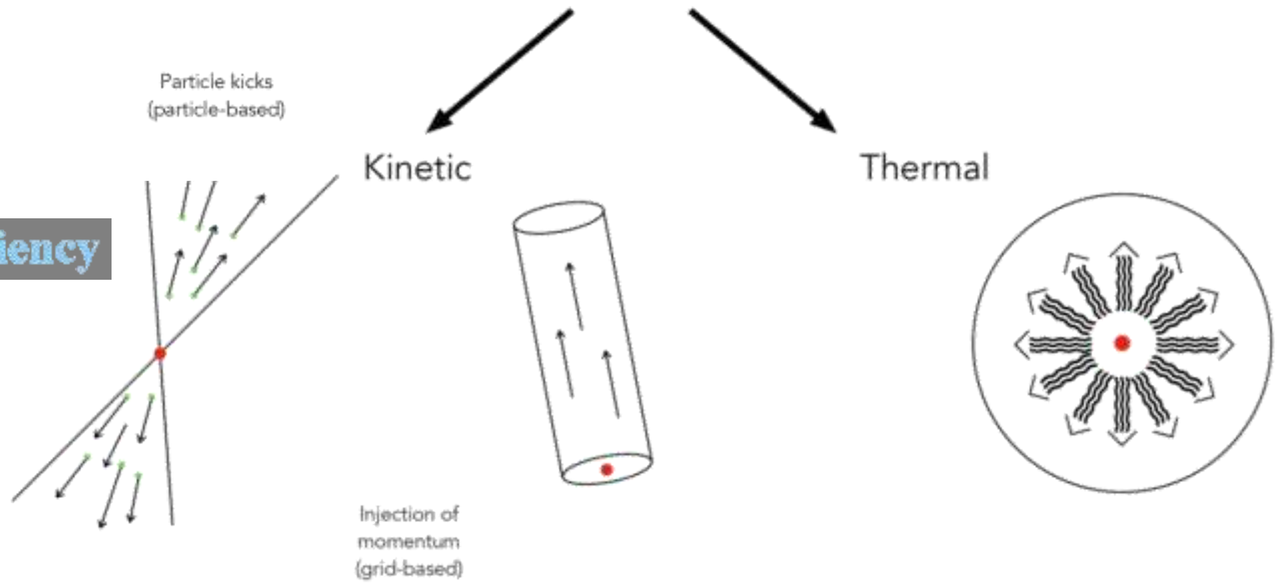
$$\eta = \epsilon_r \epsilon_f$$

ϵ_r accretion efficiency

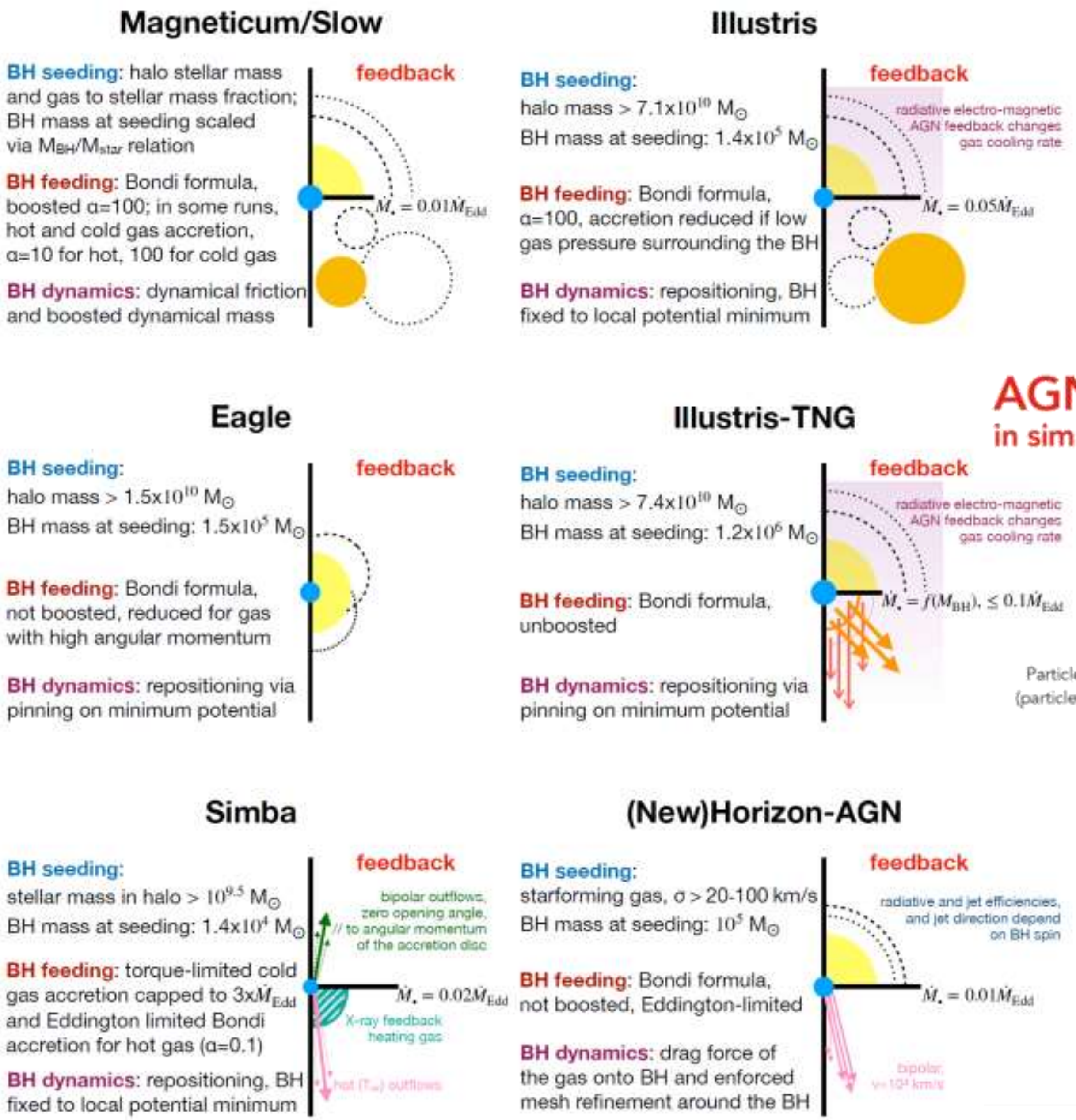
ϵ_f coupling efficiency

↑

$$\dot{E}_{\rm AGN} = \eta \dot{M}_{\rm BH} c^2$$



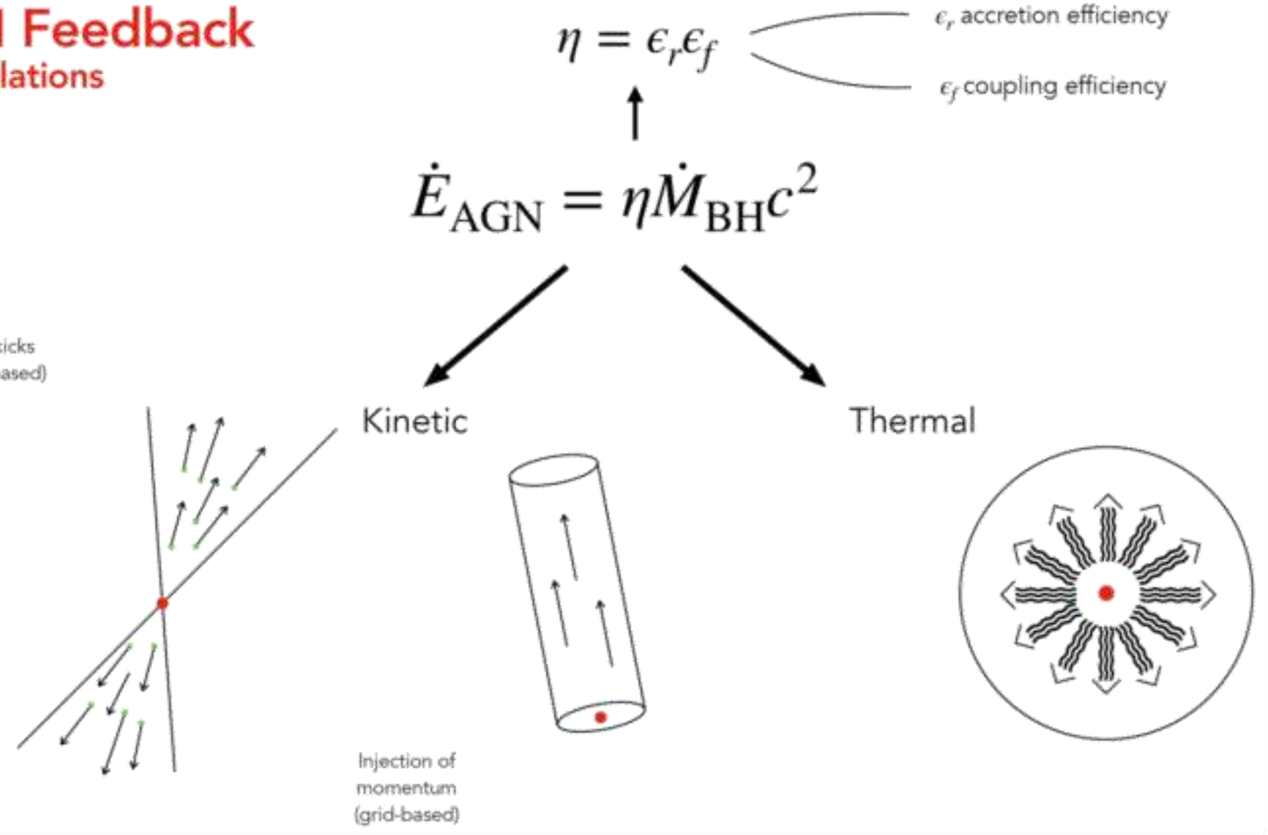
Large impact of Black Holes on galaxy evolution

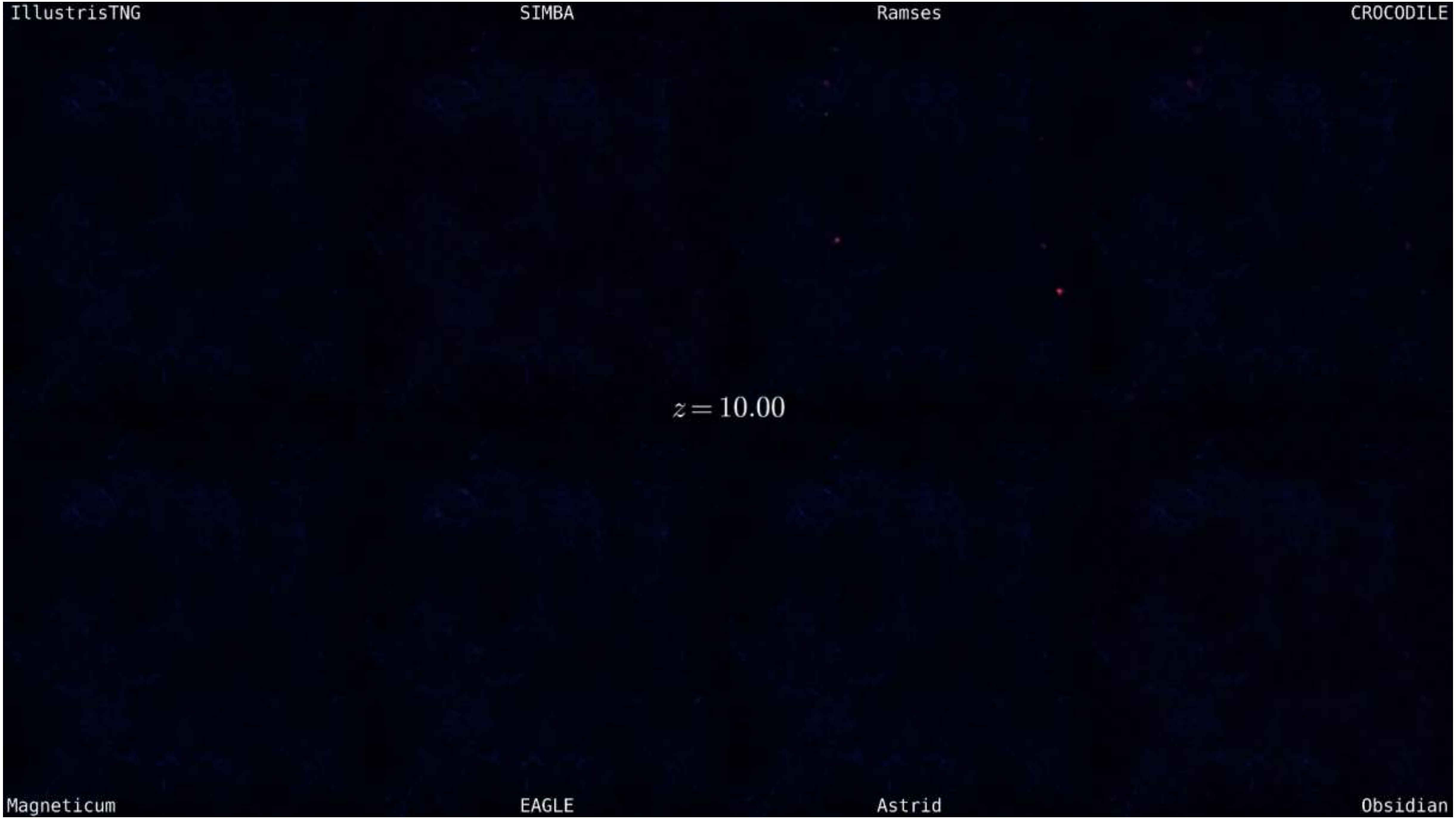


Hydrodynamic methods and sub-resolution models for cosmological simulations

Milena Valentini and Klaus Dolag

AGN Feedback in simulations

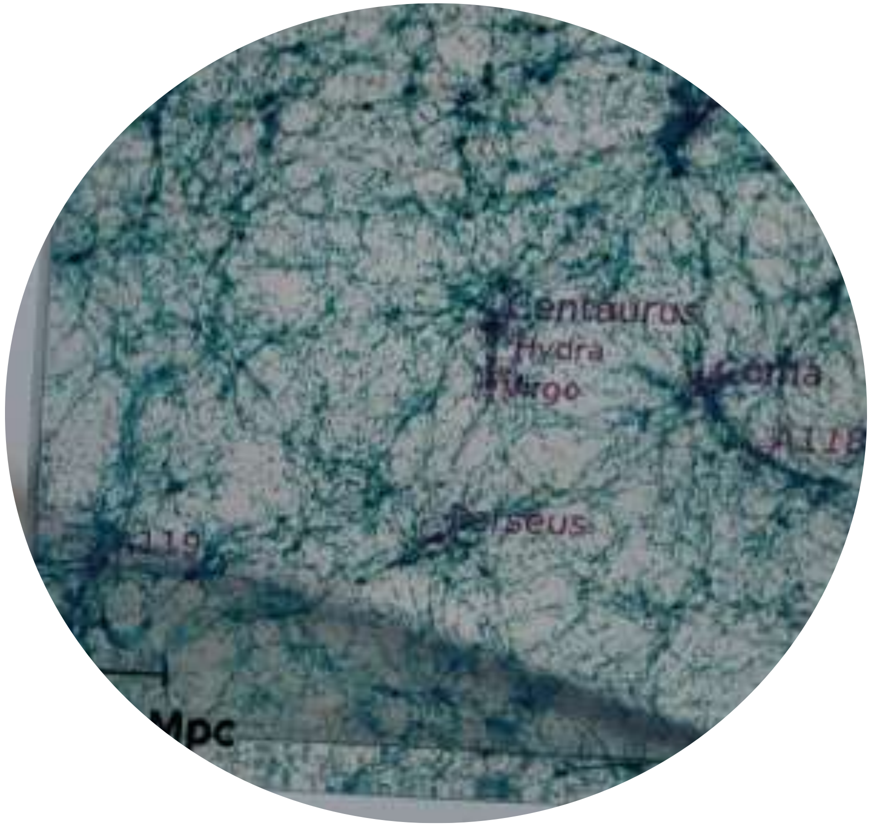




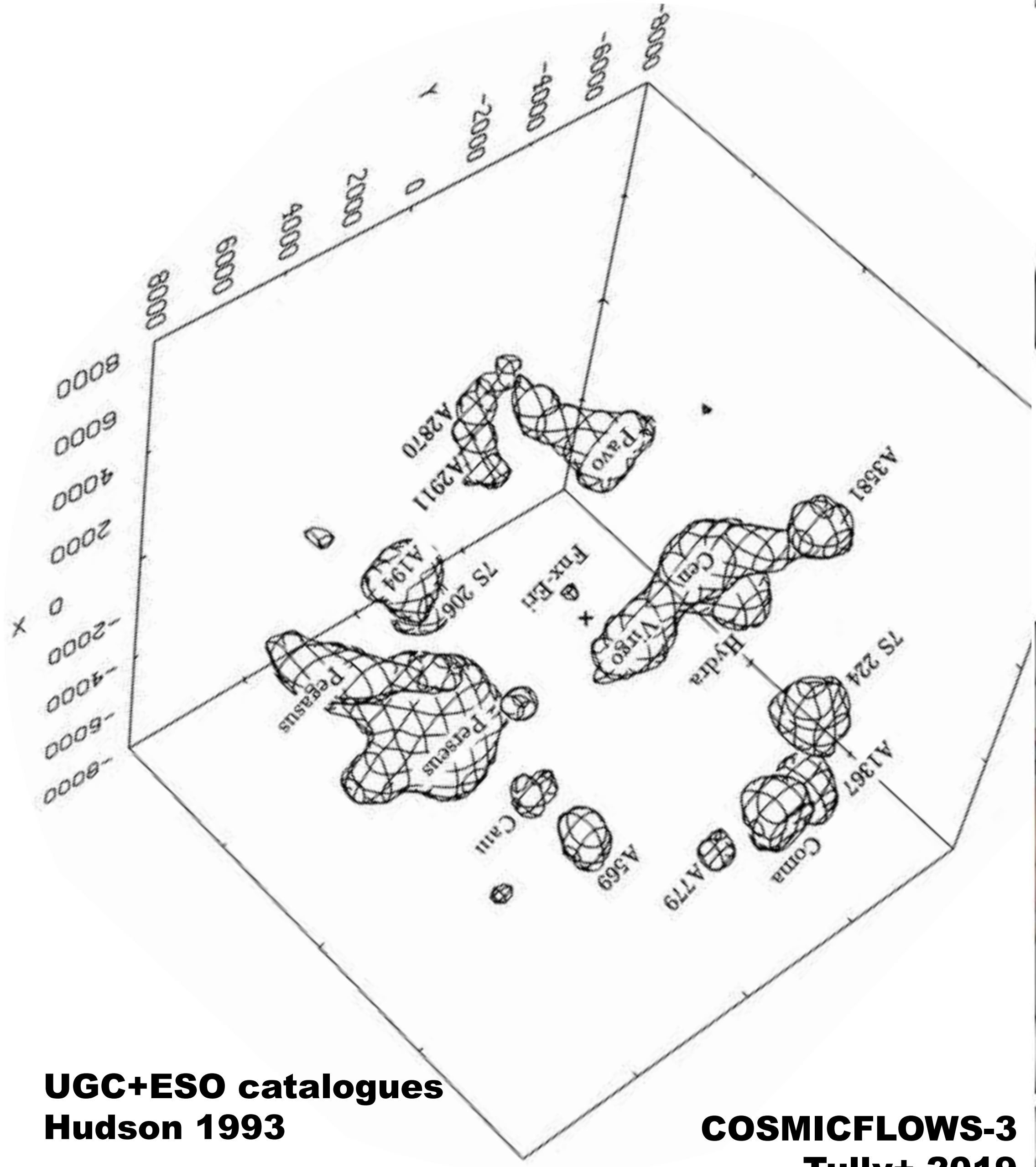
Francisco Villaescusa-Navarro (CAMELS, www.camels-simulations.org)

https://users.flatironinstitute.org/~fvillaescusa/Movies/Miscellaneous/

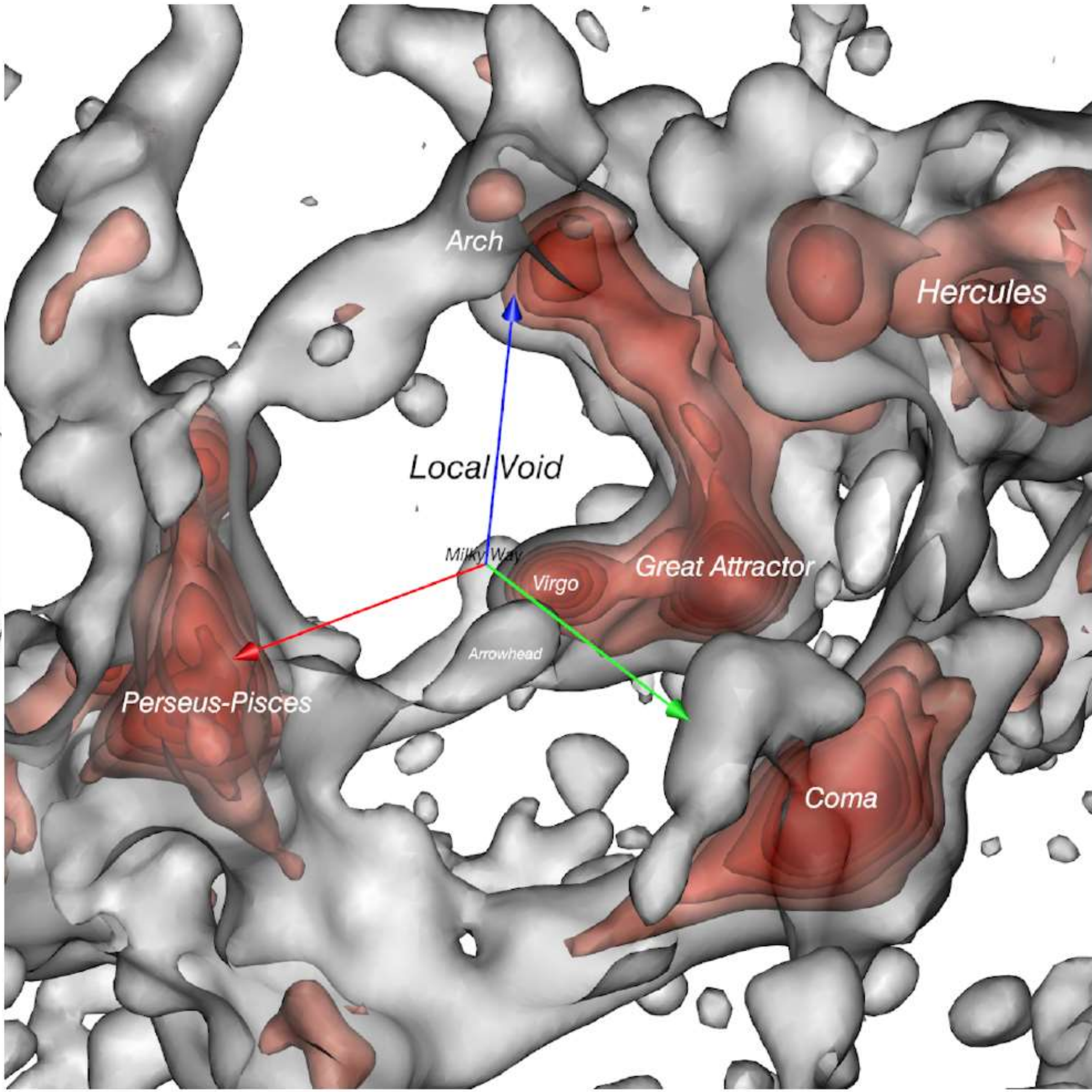
Simulations III: Towards the Local Universe


Centaurus
Hydra
Mpc

The Local Universe



UGC+ESO catalogues
Hudson 1993

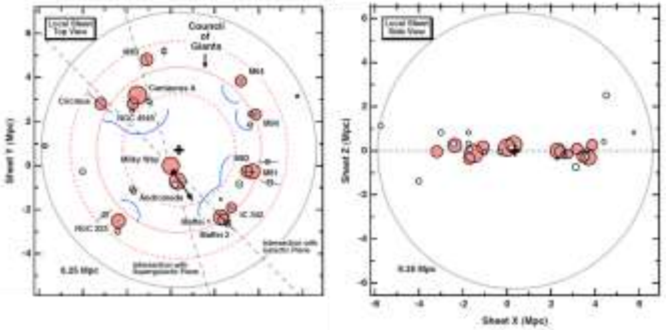


COSMICFLOWS-3
Tully+ 2019

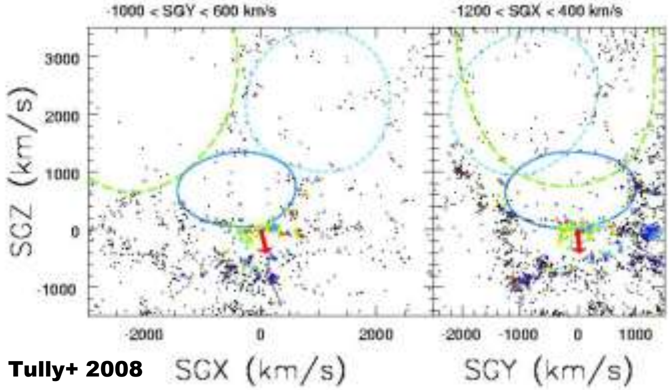
Local Universe Features

A Council of Giants

McCall 2014

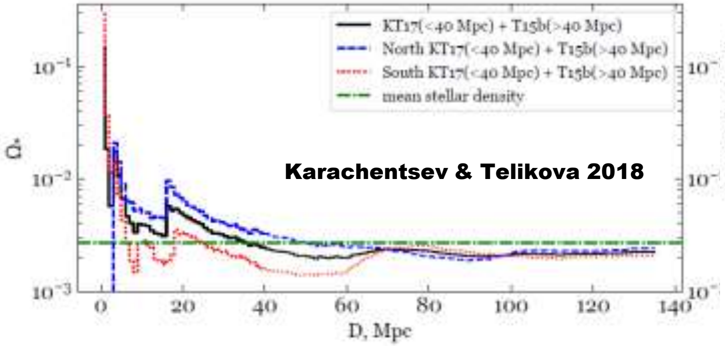


Our Peculiar Motion Away from the Local Void

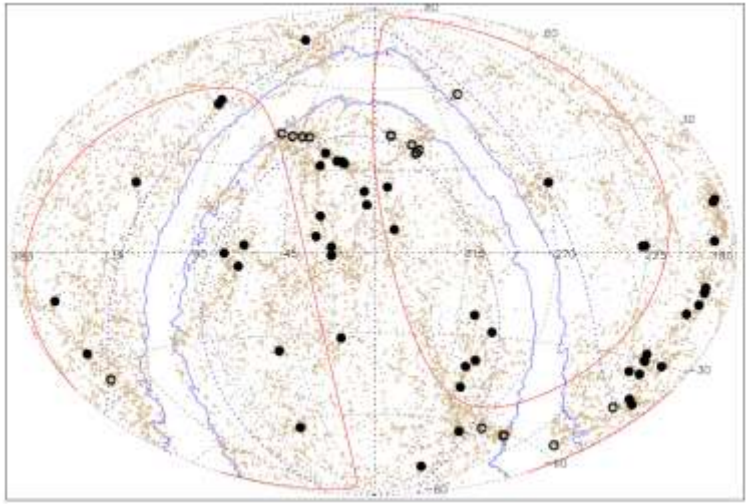


Tully+ 2008

Stellar and dark matter density in the Local Universe



Karachentsev & Telikova 2018

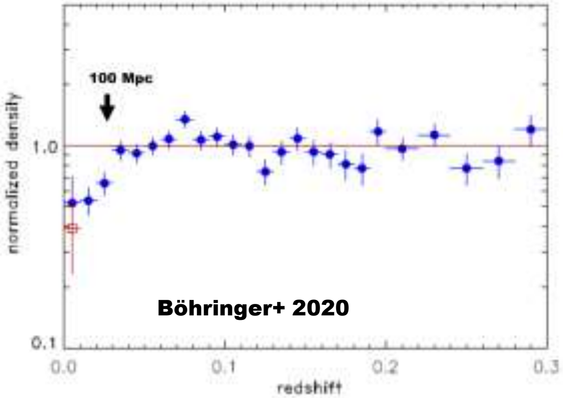


The Cosmic Large-Scale Structure in X-rays (CLASSIX) Cluster Survey II: Unveiling a pancake structure with a 100 Mpc radius in the local Universe *

Hans Böhringer[1,2], Gayoung Chon[1], Joachim Trümper[2]

See also Reviews:
Flin 1986
Rubin 1989
Lahav+ 2000
Peebles 2022

Observational evidence for a local underdensity in the Universe and its effect on the measurement of the Hubble Constant *



Böhringer+ 2020

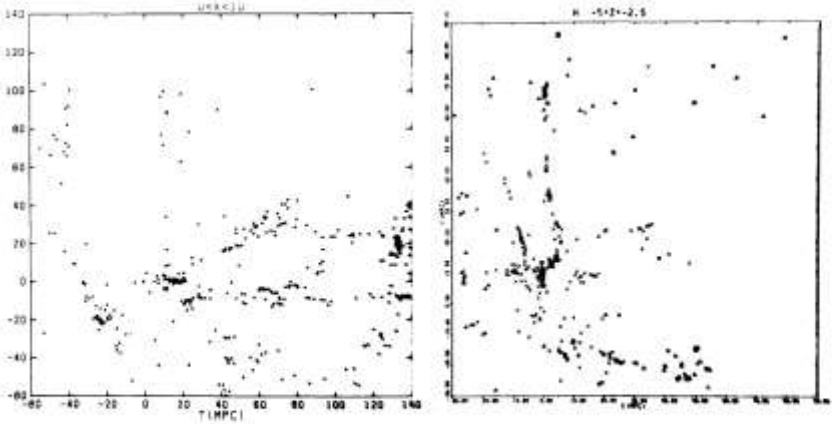


Figure 4. Thin slices through the Local Supercluster, in SG coordinates, corresponding to Hubble constant 100.

NEIGHBORING SUPERCLUSTERS AND THEIR ENVIRONS

J. Einasto[1] and R.H. Miller[2]
[1]Tartu Astrophysical Observatory
[2]European Southern Observatory

Einasto & Miller 1983

Recently finished redshift surveys make it possible to study the large-scale environment of superclusters and their mutual relationship.

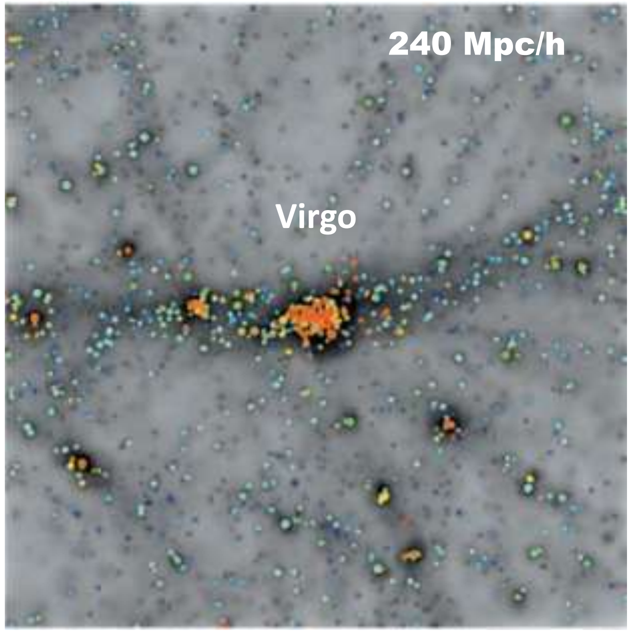
Figure 1 shows the distribution of nearby clusters in the sky in supergalactic coordinates at two redshift intervals. Nearby clusters in the distance interval 75 to 150 Mpc form a belt around us which is close to the supergalactic equator; its inclination is only 20°. The following superclusters belong to this belt: Ursa Major-Lynx (Giovanelli and Haynes 1982), Coma, Hydra-Centaurus, Pavo-Corona Australes, and Perseus-Pisces. Coordinates and redshifts for a number of previously unknown southern clusters have been derived by Dr. H. Corwin and Dr. M. Tarenghi (Einasto et al. 1982).

Clusters in the distance interval 150 to 250 Mpc are found at much higher supergalactic latitudes. Clusters in this distance interval form a number of superclusters: Hercules, Ursa Major-Leo, Pegasus and several southern superclusters.

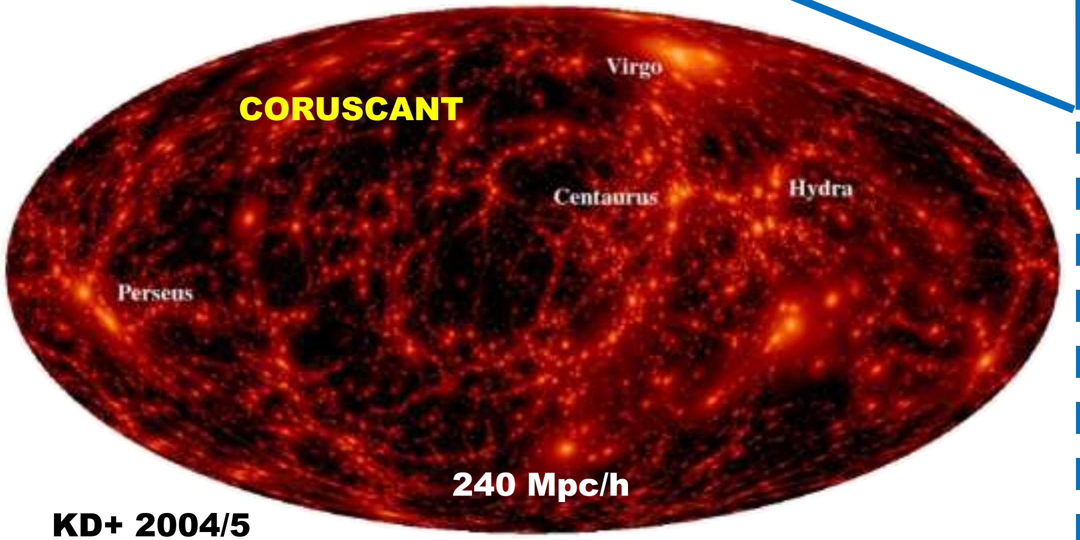
All these superclusters belong to cells which can be called the Northern Local Cell and the Southern Local Cell (Einasto et al. 1982). Nearby superclusters form together with our Local Supercluster a disk about 250 Mpc in diameter and 50 Mpc thick, which is located between both local cells. The Hercules supercluster is located between the Northern Local Cell and The Bootes cell, studied by Kirsher et al. (1981). The Perseus-Pisces and Pegasus superclusters are located between the Northern Local Cell and the Perseus cell.

Local Universe Simulations

Density based (redshift surveys)

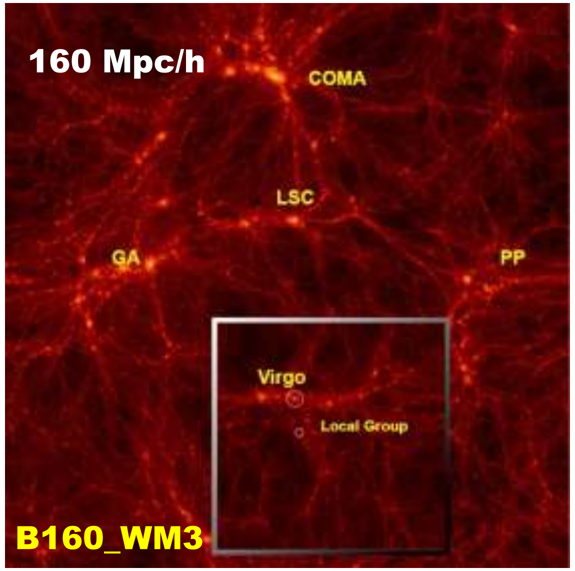


Mathis+ 2002



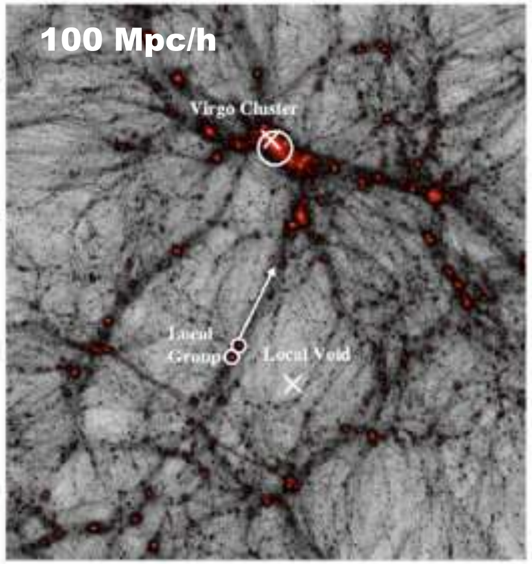
KD+ 2004/5

Hybrid approach

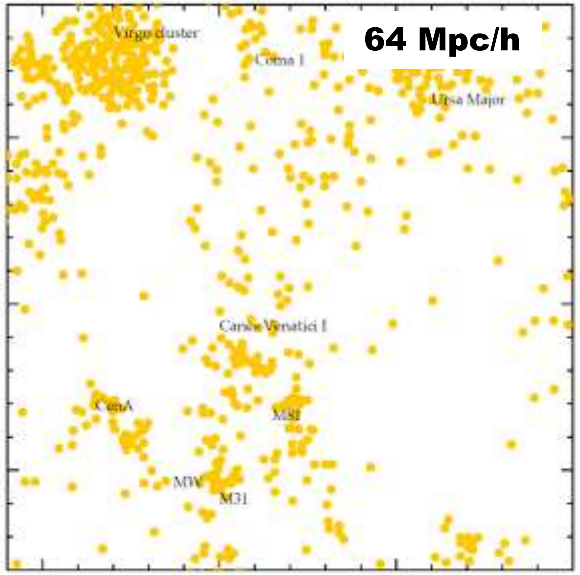


Klypin+ 2003 / Gottlöber+ 2010

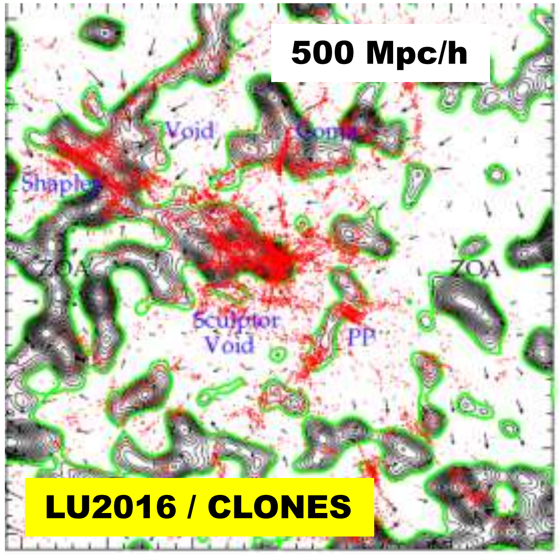
Velocity based
(peculiar velocity derived from distance measures)



Liebeskind+ 2016+



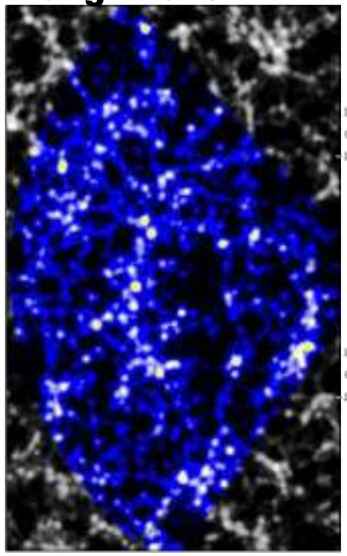
Ocvirk+ 2020, Sorce+ 2022

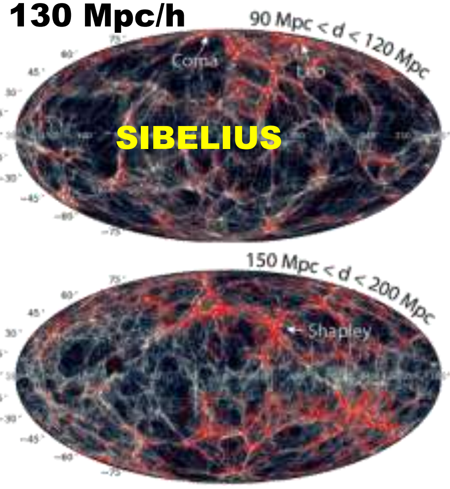


Sorce 2016, 2018

Bayesian forward modelling

Wang+ 2016

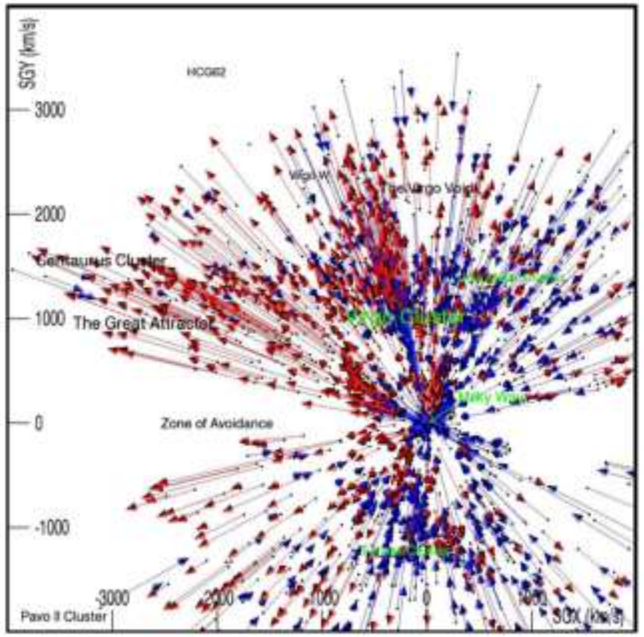


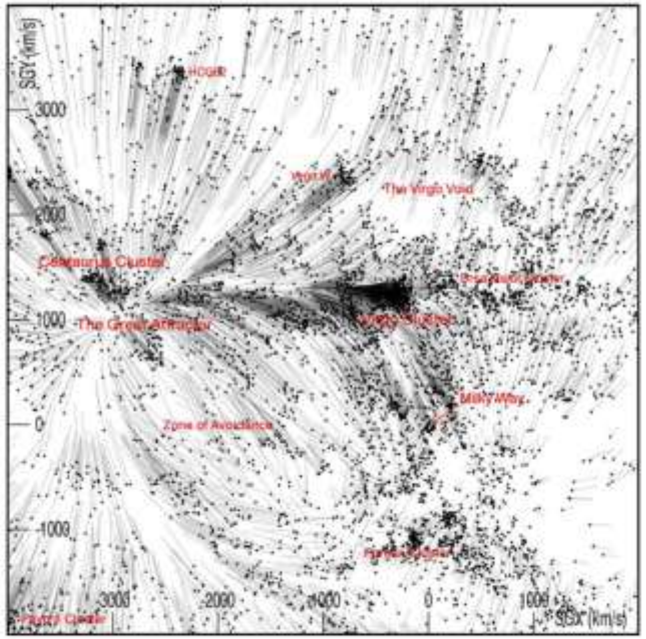


McAlpine 2022

Some details what is done for ICs

Here, details are worked out / improved continuously over last decade. Especially through contributions by J. Sorce.





Method

Radial peculiar velocity catalog

↓

Grouping

↓

Minimization of biases

↓

Wiener filtering

↓

Reverse Zel'dovich Approximation

↓

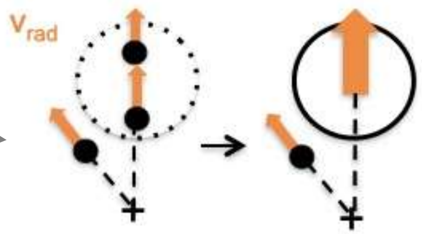
Constrained realization

↓

Constrained initial conditions

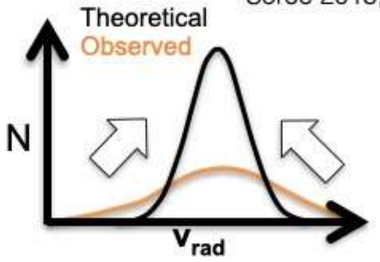
Obtaining linear component of the velocity field.

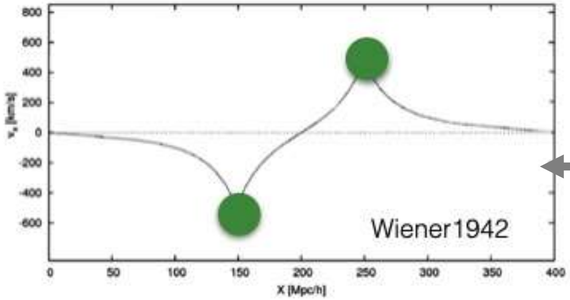
Sorce & Tempel 2017,2018



Bias minimization
Malmquist bias & lognormal errors

Sorce 2015, 2018

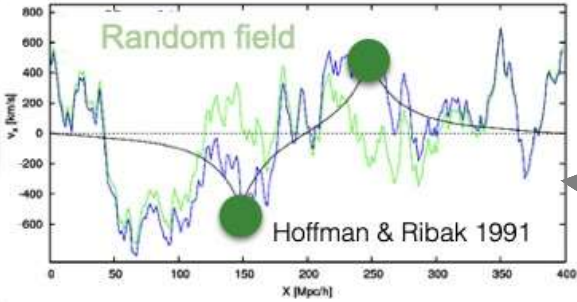




Reconstruct the displacement field

Doumler+2013 Sorce+2014

Relocating constrains



Combine with random realization for missing structures.

Sorce2018, Sorce et al. 2021, etc.

Slice kindly provided by J. Sorce

Simulating the LOcal Web

Box of 500 Mpc/h

Several hundreds of dark matter only test simulations

Two production runs:

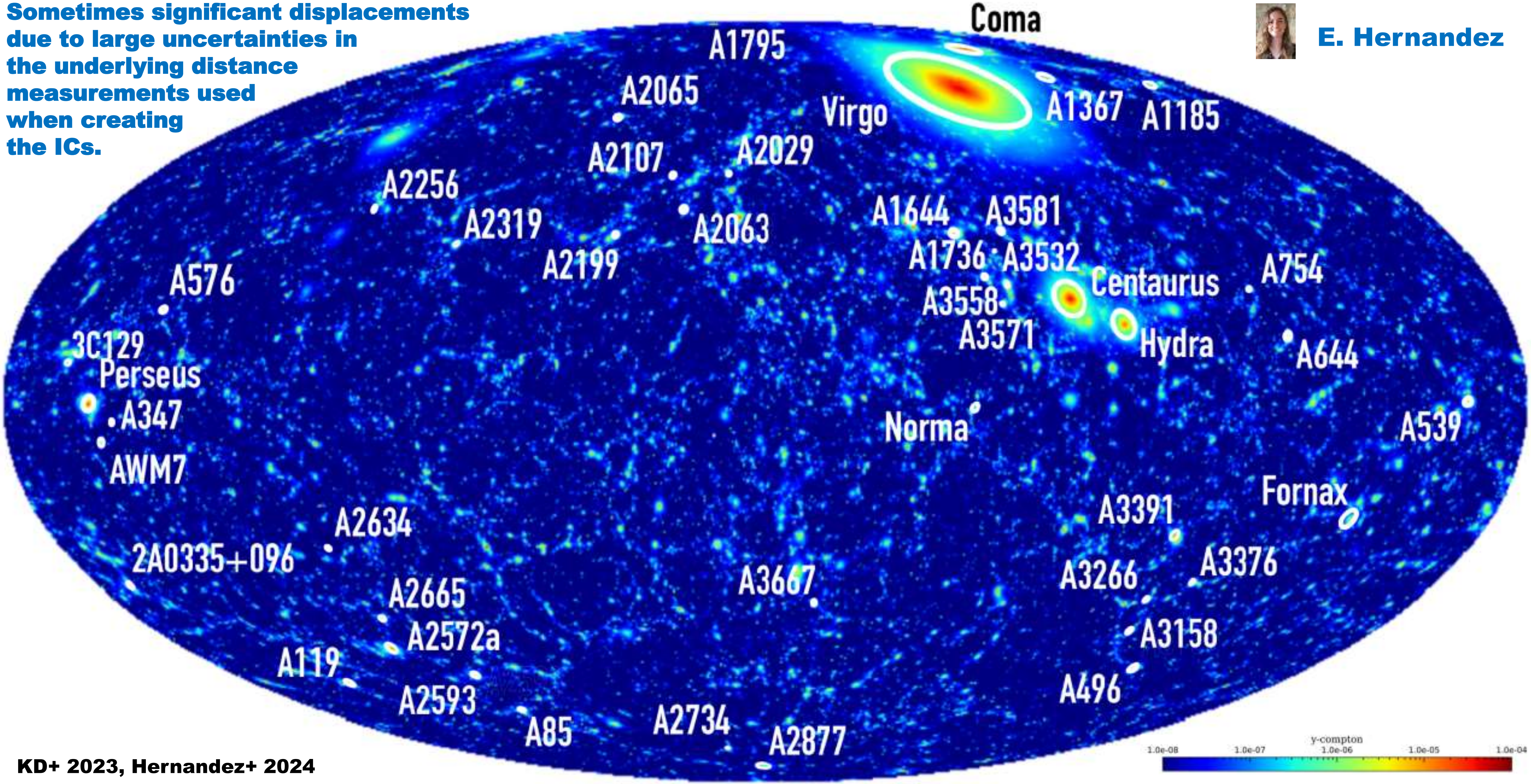
- ❑ **$2x1536^3$ full galaxy formation physics, including AGN (AGN)**
- ❑ **$2x3072^3$ non radiative MHD with cosmic rays (MHD+CRs)**

The SLOW simulation

Cross identified more than 45 Clusters between simulations and observational catalogues (like CLASSIX, PLANCK, …)

Sometimes significant displacements due to large uncertainties in the underlying distance measurements used when creating the ICs.

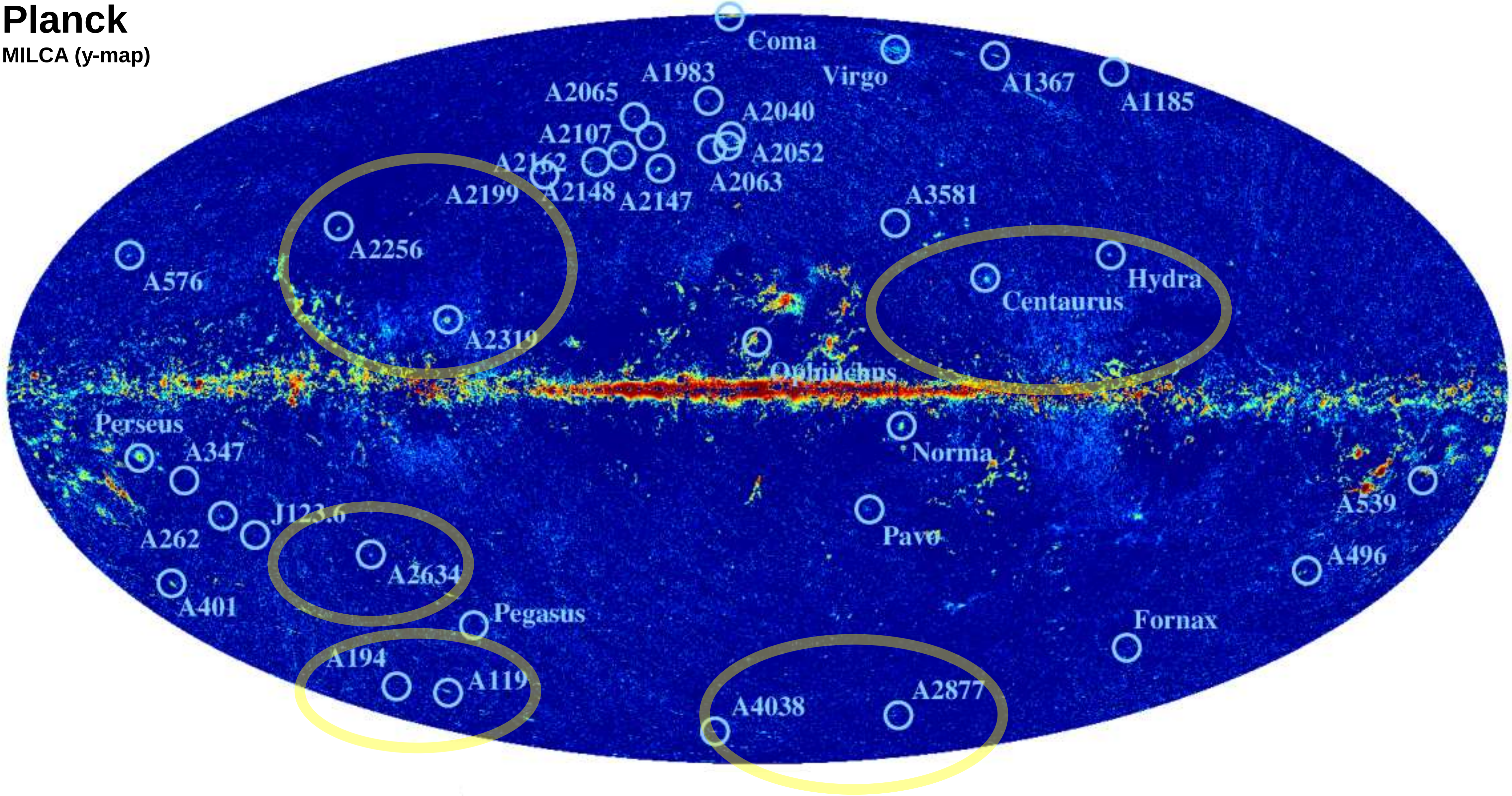
E. Hernandez



KD+ 2023, Hernandez+ 2024

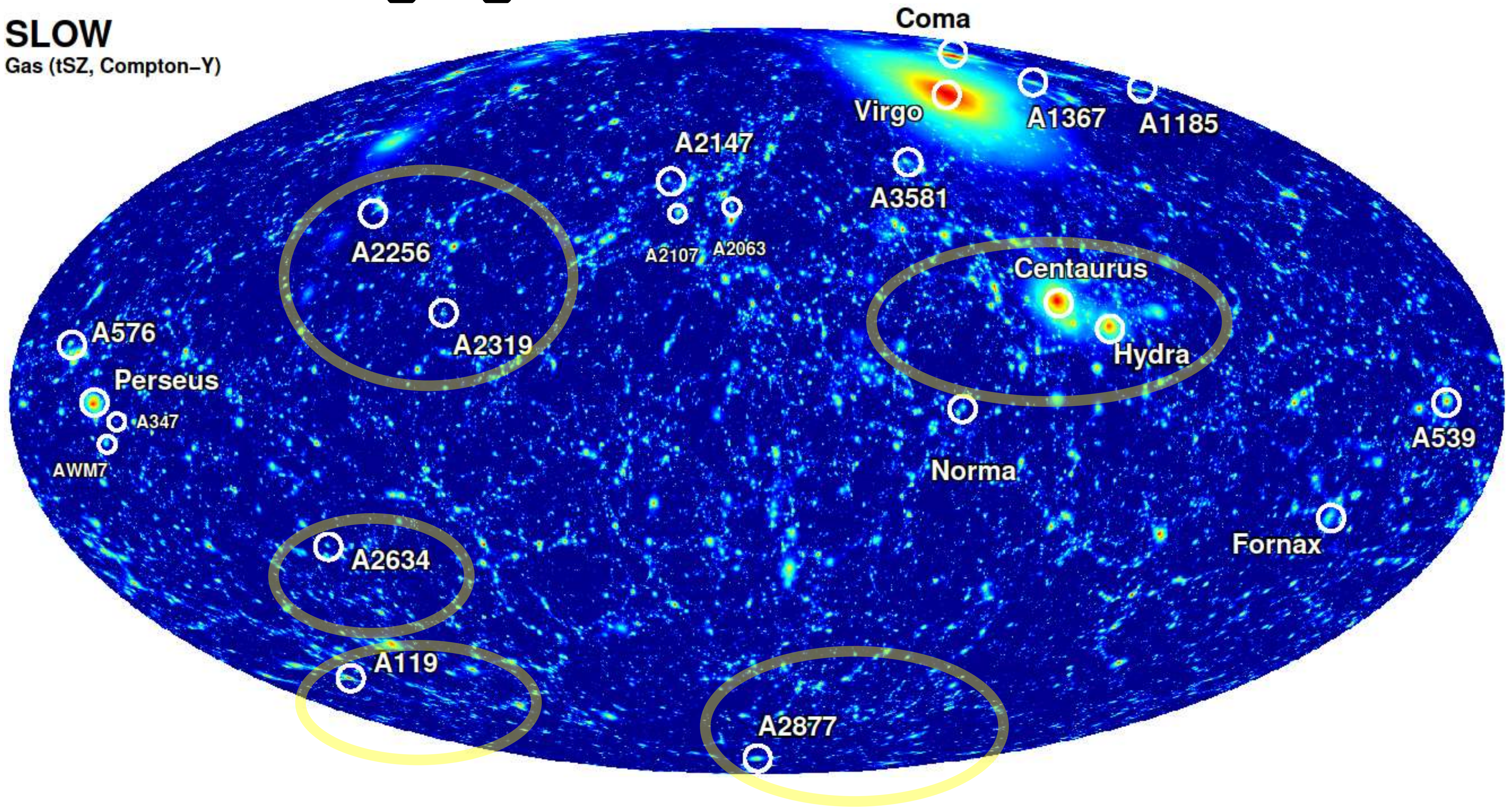
Matching against the SLOW simulations

Planck
MILCA (y-map)



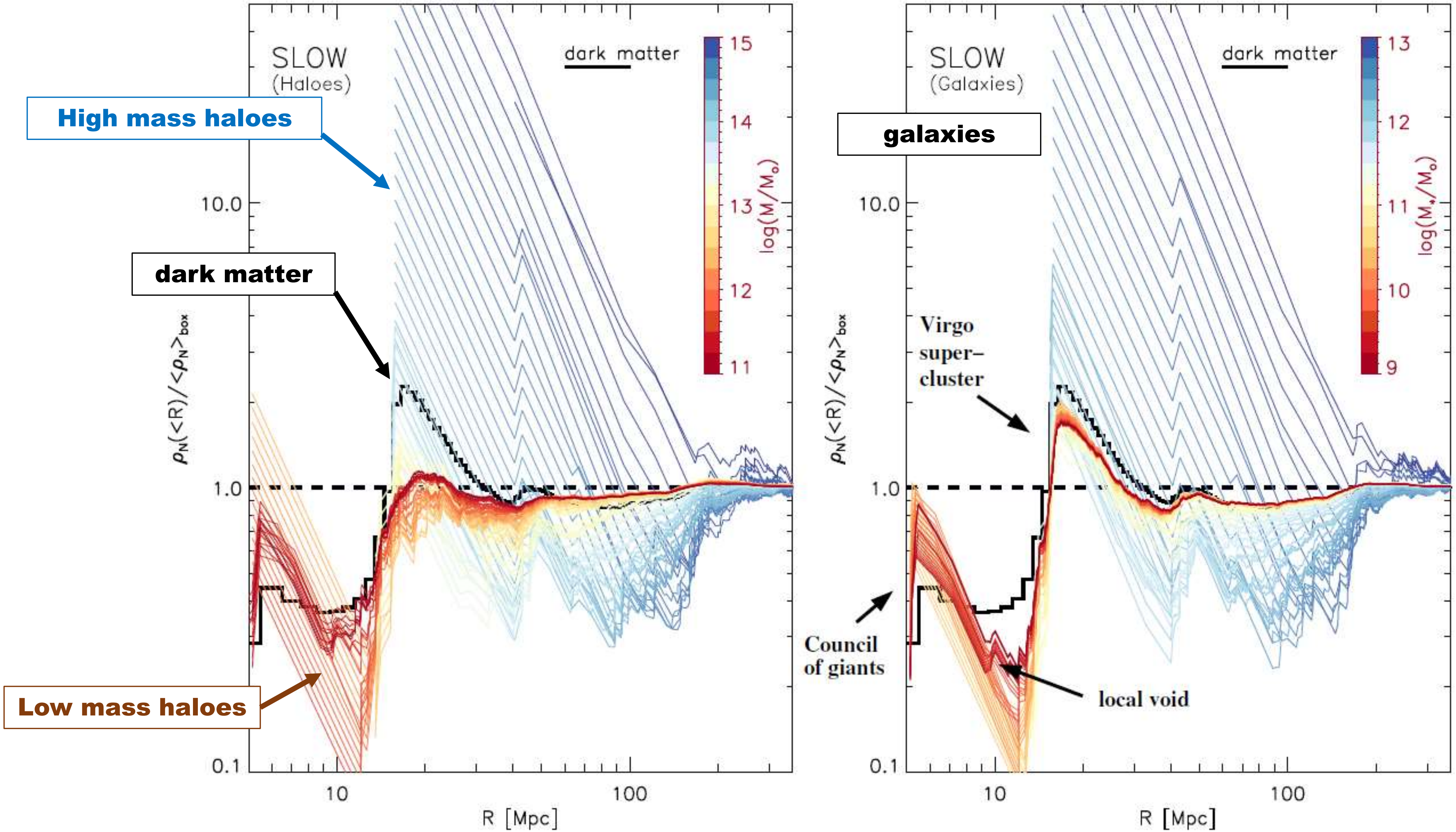
Some twist in sky positions by residuals in velocity bias/reconstruction

Matching against the SLOW simulations

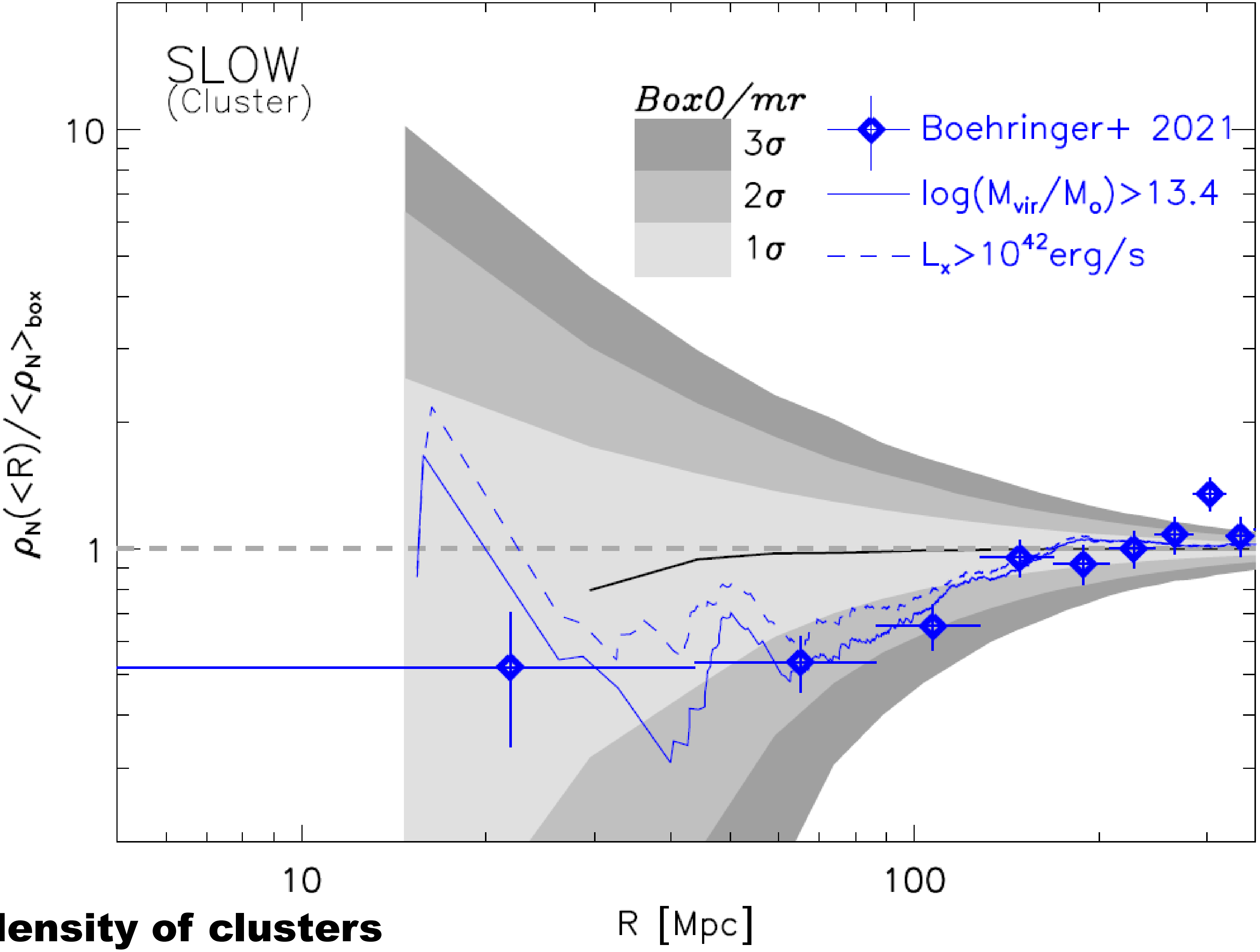


Some twist in sky positions by residuals in velocity bias/reconstruction

The SLOW simulation: matter distribution and tracers

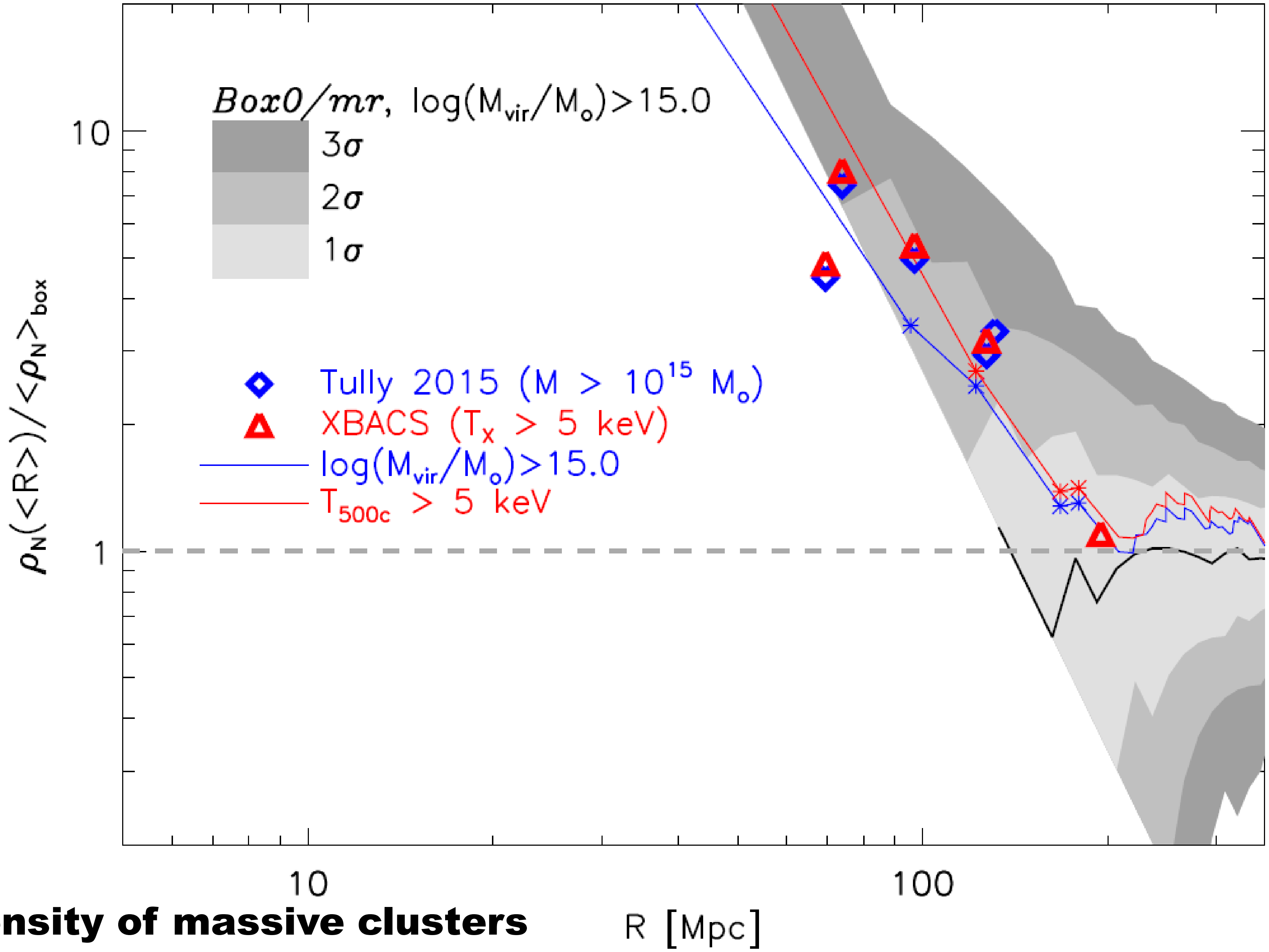


The SLOW simulation: matter distribution and tracers



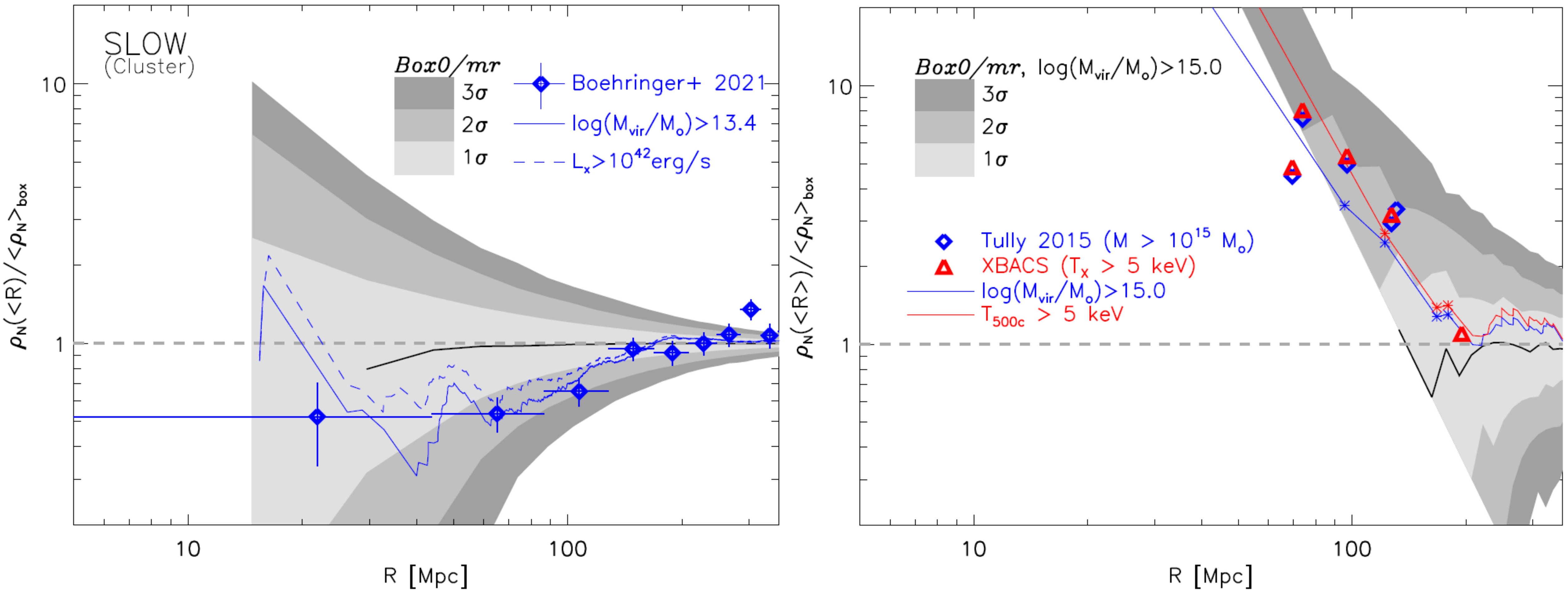
local under density of clusters

The SLOW simulation: matter distribution and tracers



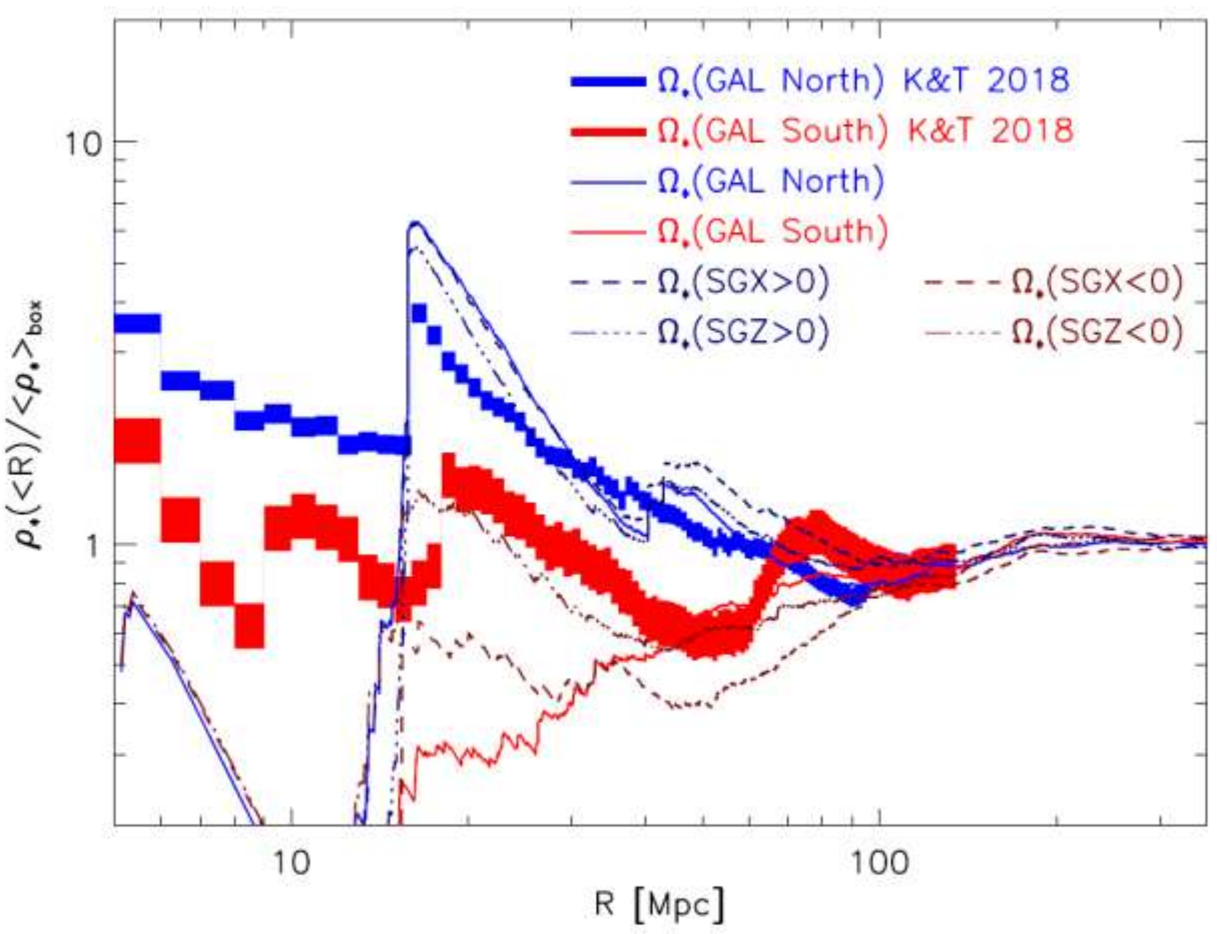
local over density of massive clusters

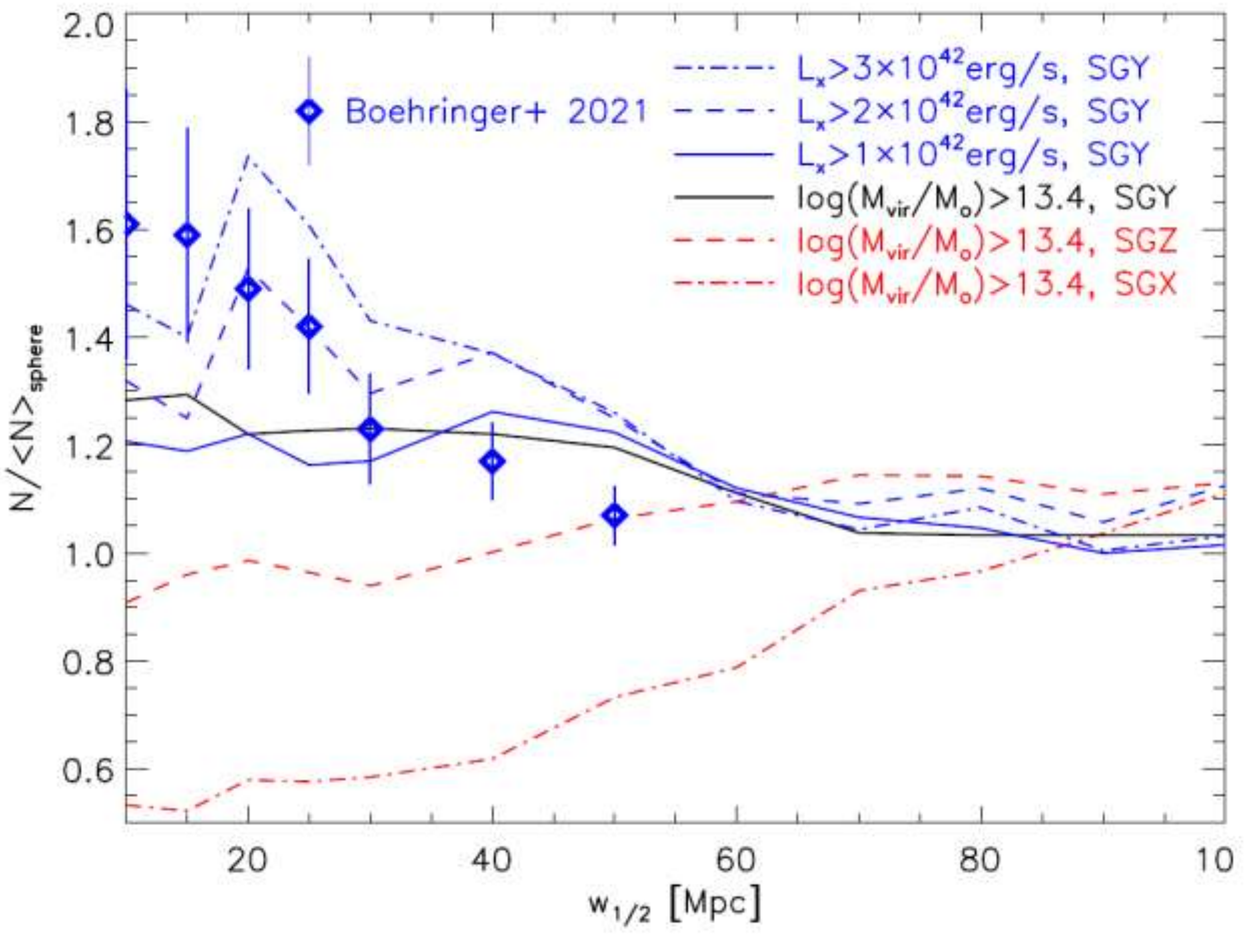
The SLOW simulation: matter distribution and tracers



Only 44 out of 15635 regions from Box0 are matching (>3σ !)

The SLOW simulation: matter distribution and tracers

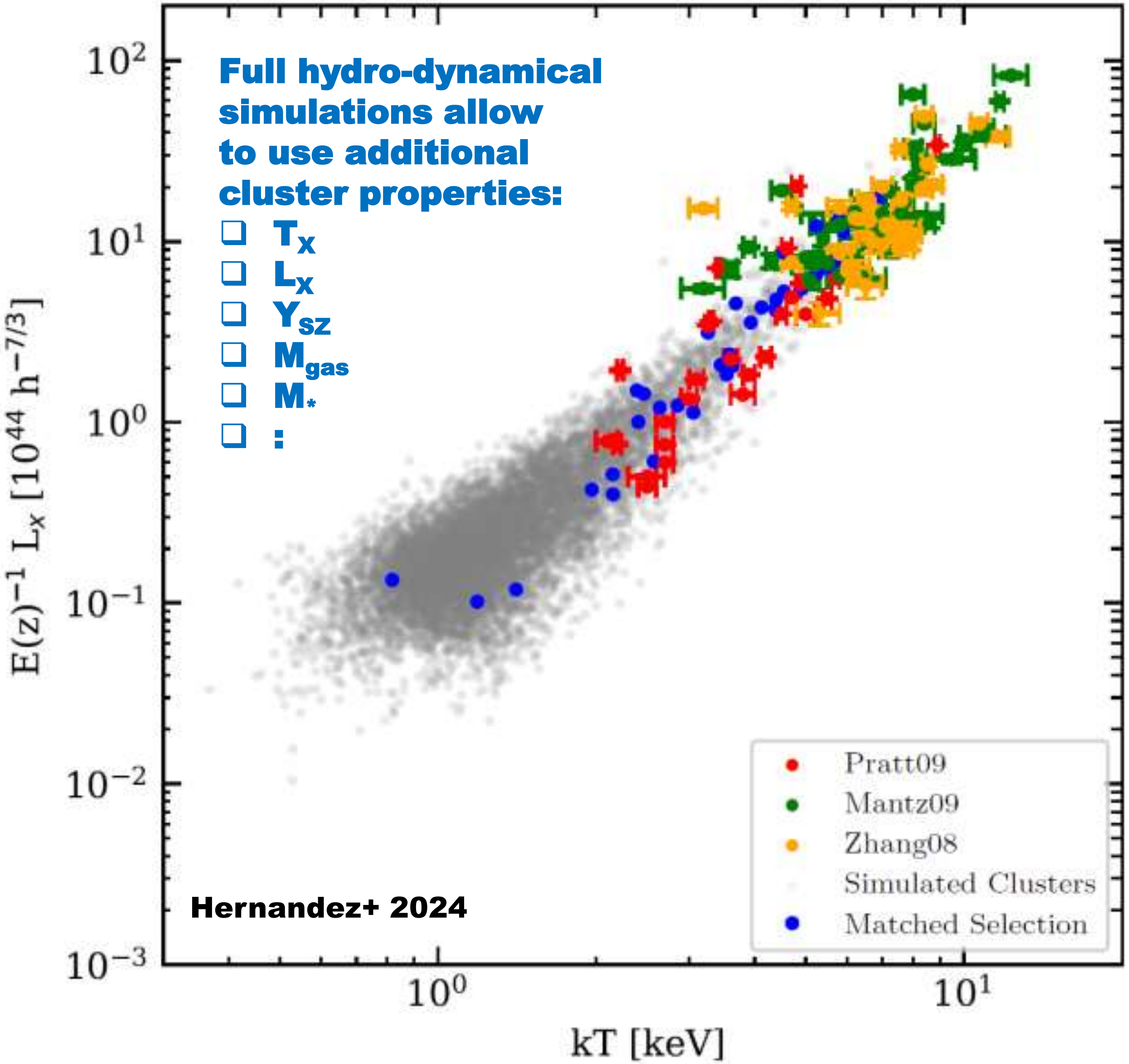




- ❑ **Pancake like structure traced by clusters reproduced**
- ❑ **Density structures and north/south split in galaxies reproduced at large R**
- ❑ **Density in stars closer than 20 Mpc not well represented**

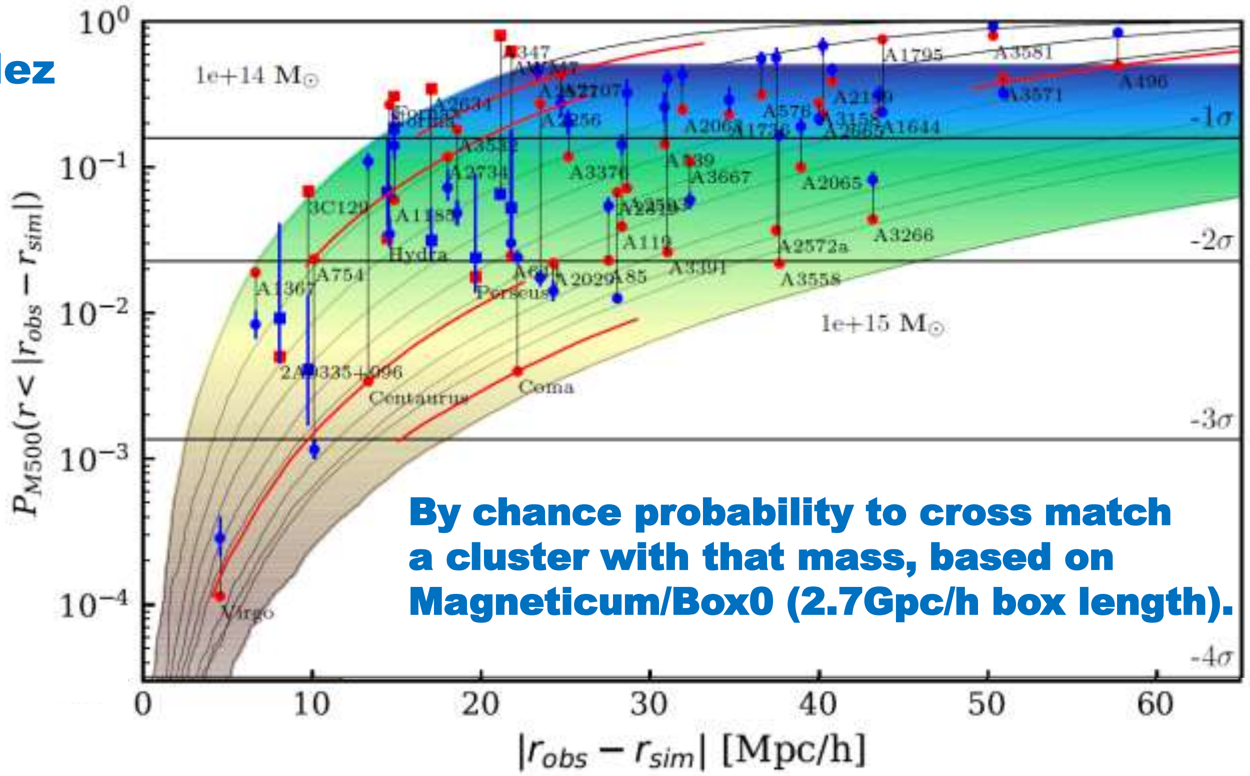
The SLOW simulation

E. Hernandez

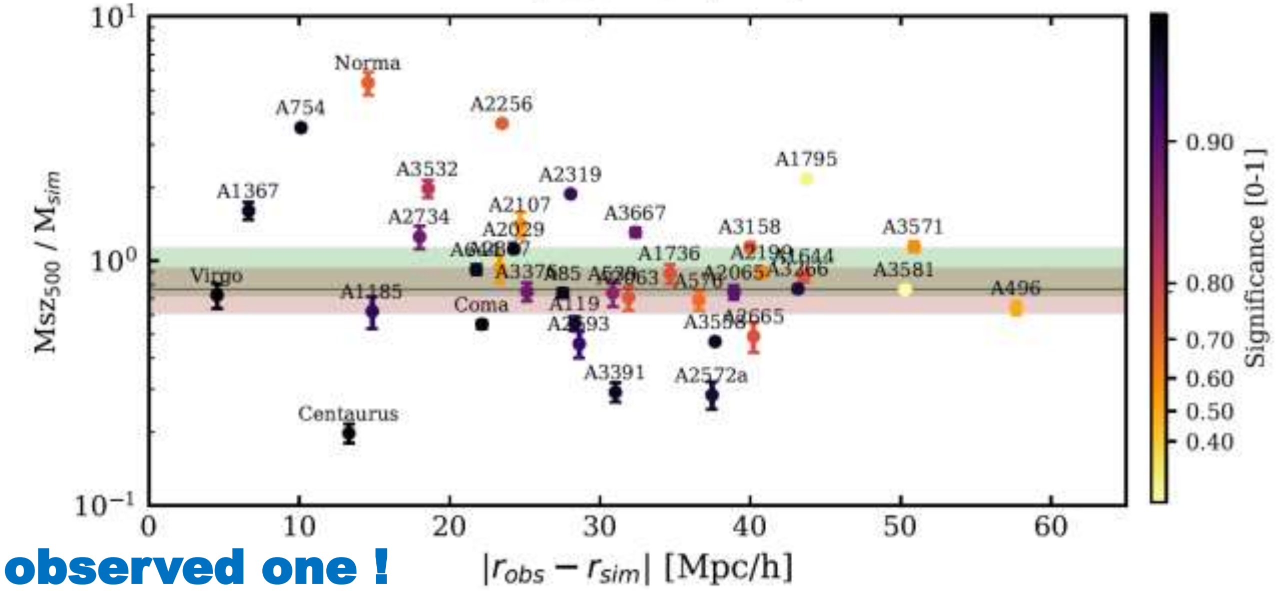


Full hydro-dynamical simulations allow to use additional cluster properties:

- ❑ T_X
- ❑ L_X
- ❑ Y_{SZ}
- ❑ M_{gas}
- ❑ M_*
- ❑ :



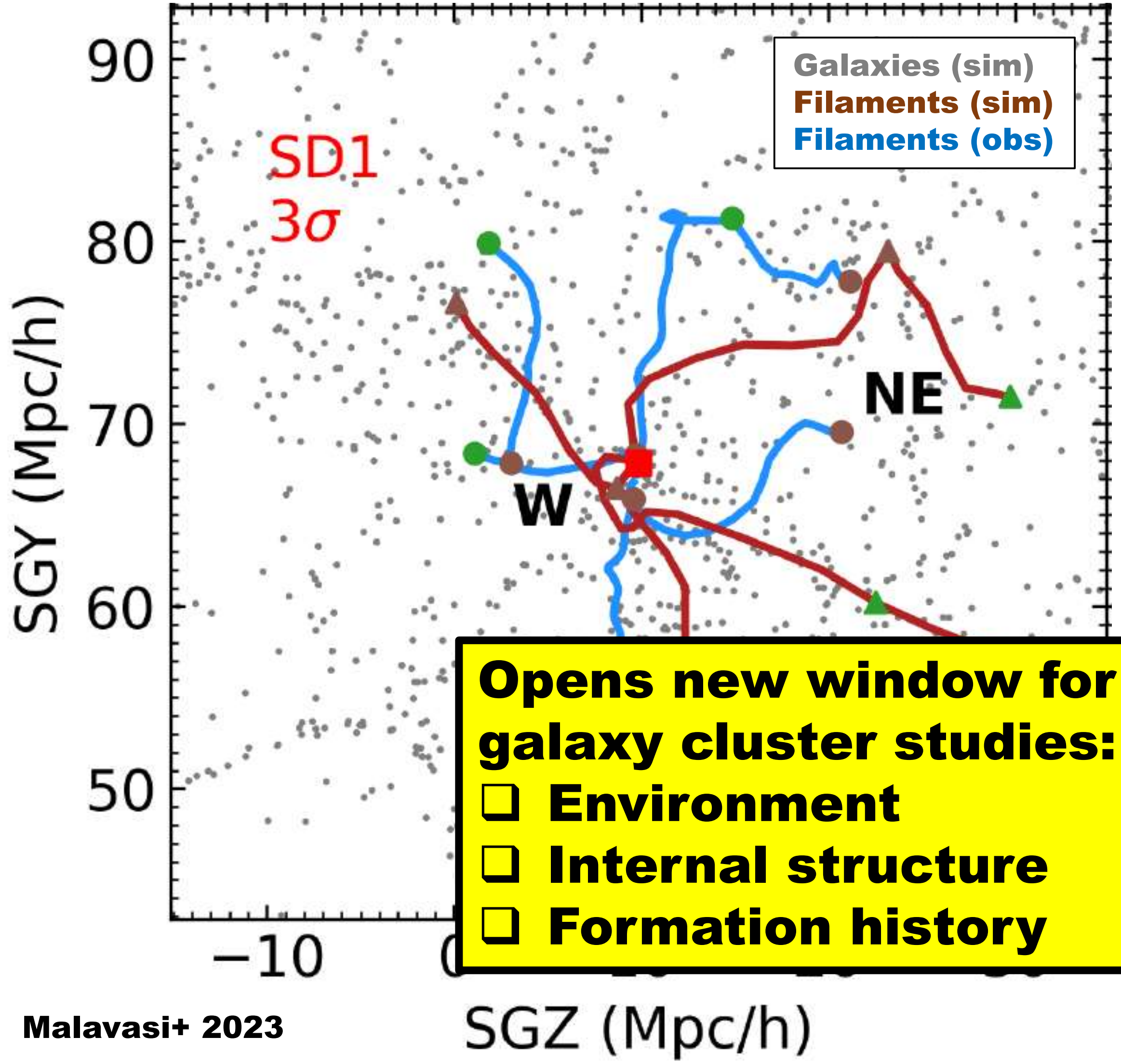
By chance probability to cross match a cluster with that mass, based on Magneticum/Box0 (2.7Gpc/h box length).



- ❑ **On average, the simulated mass matches the observed one !**
- ❑ **The ratio of observed to simulation mass indicate a hydrostatic mass bias (1-b) ~ 0.87 …**

The SLOW/CLONES simulation

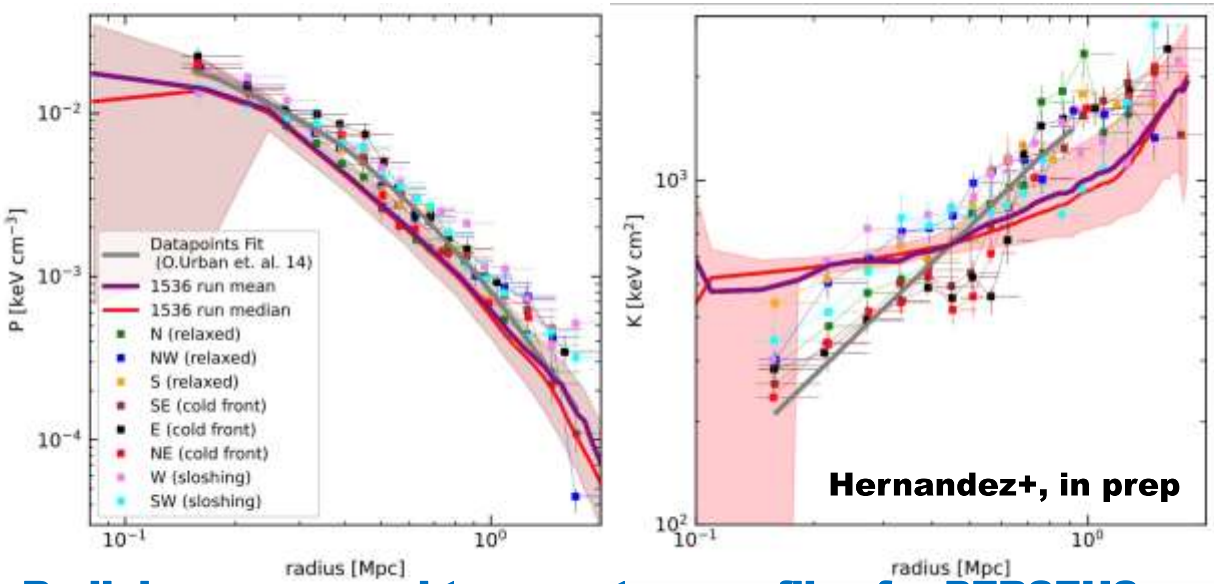
Filaments detected using DISPERSE in a zoom-in simulation of Coma from CLONES (DM only, RAMSES) compared with the ones detected in DSS.



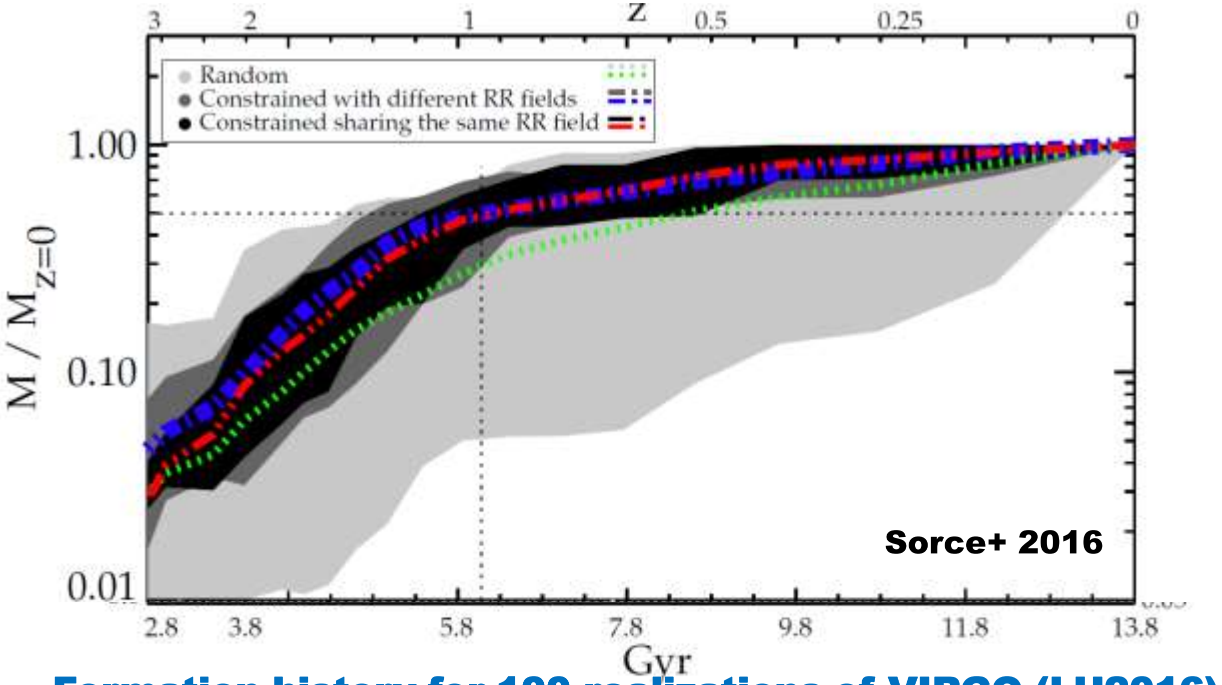
Opens new window for galaxy cluster studies:

- ❑ **Environment**
- ❑ **Internal structure**
- ❑ **Formation history**

Malavasi+ 2023



Radial pressure and temperature profiles for PERSEUS (SLOW, AGN1576 run) compared to X-ray observations.



Formation history for 100 realizations of VIRGO (LU2016) compared to randomly selected haloes with equal mass.

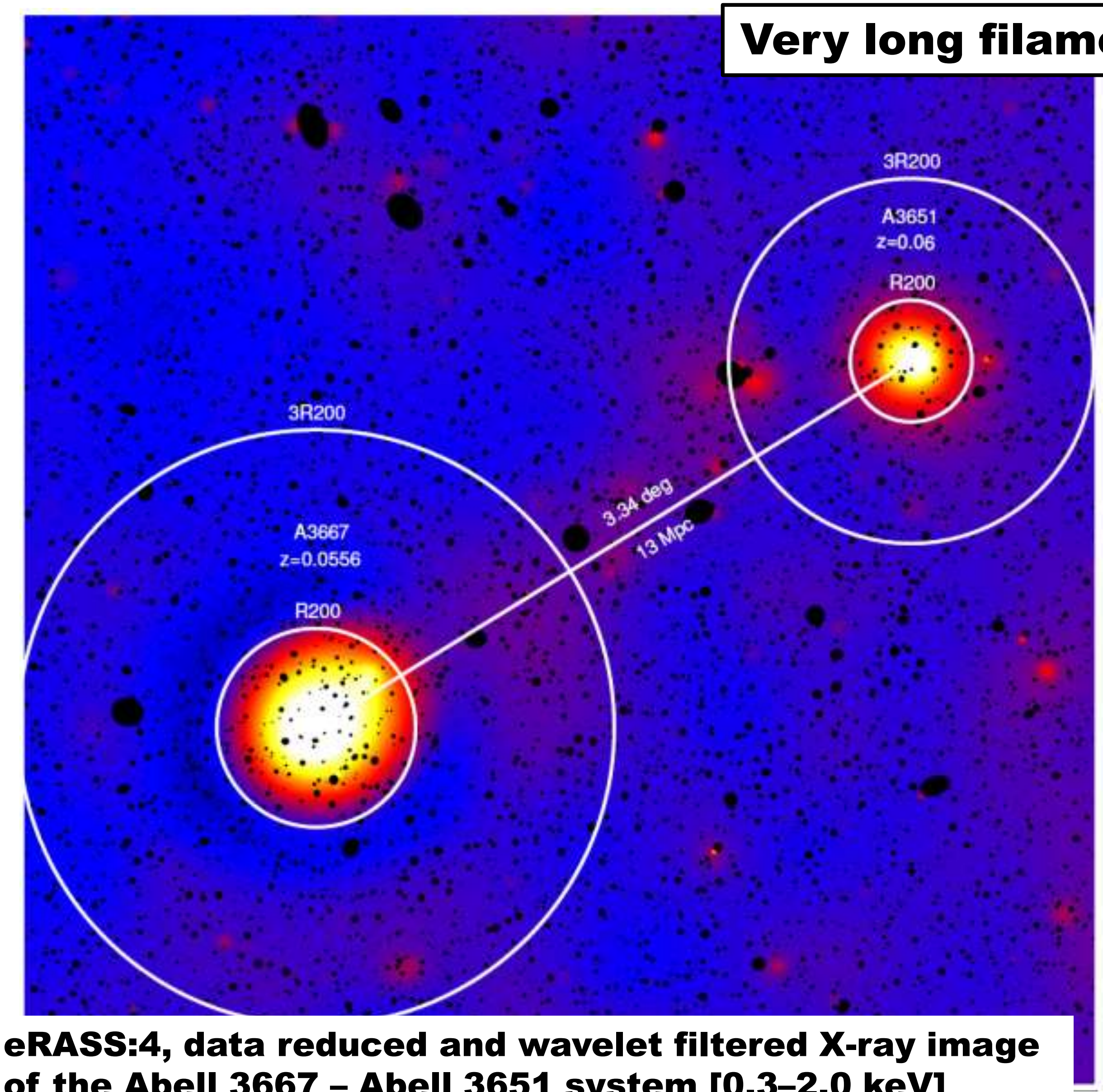
What can we learn?

An eROSITA filament with a counterpart in SLOW?

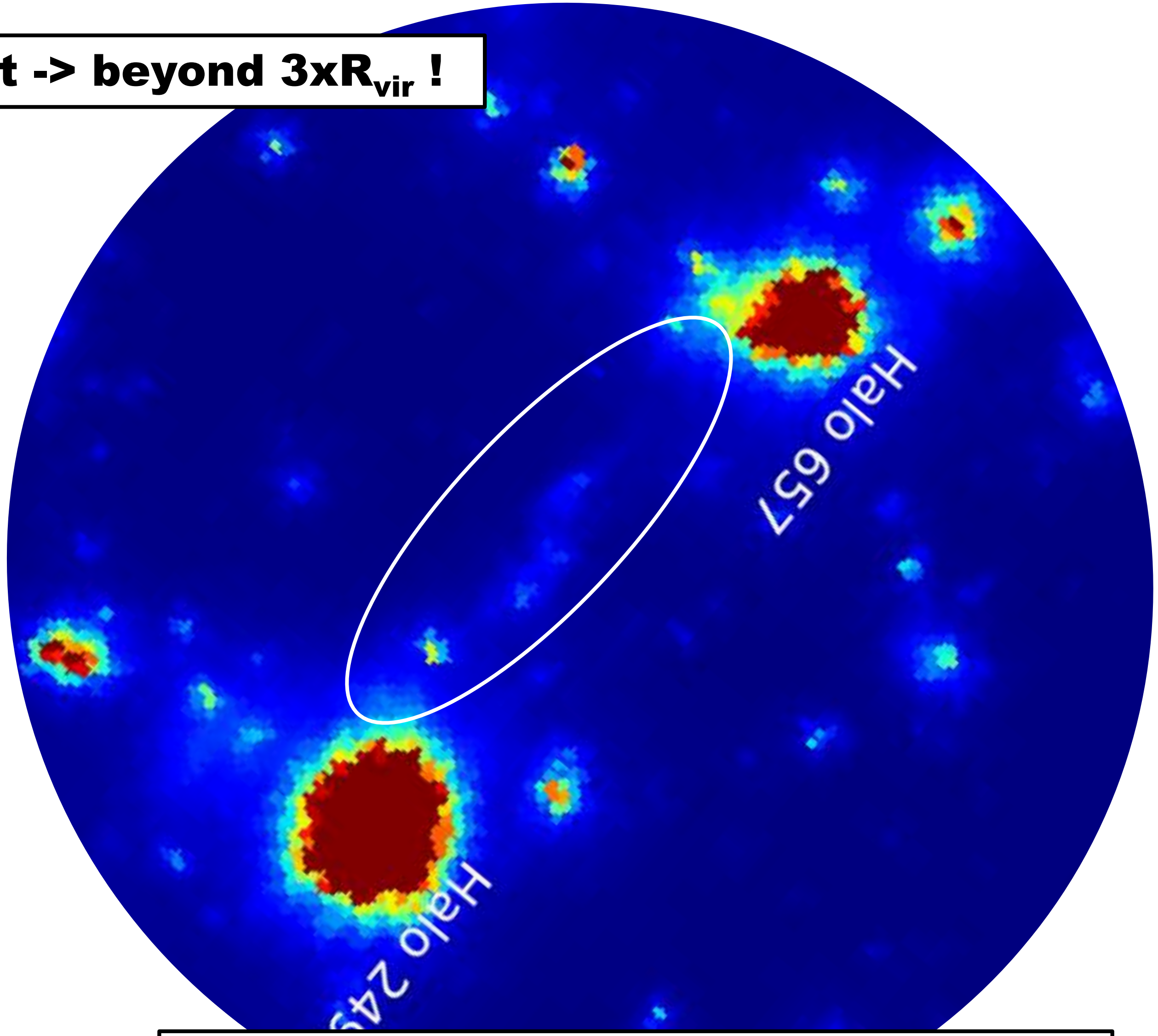
Filament between the cross identified clusters in SLOW

B. Seidel

Very long filament -> beyond $3xR_{vir}$!



eRASS:4, data reduced and wavelet filtered X-ray image of the Abell 3667 – Abell 3651 system [0.3–2.0 keV]
Dietl+ 2024



1) **The clusters will not merge!**
2) **Filament is bright as it is a merged structure out of 2 filaments!**

Coma in shining in radio in SLOW

L. Böss

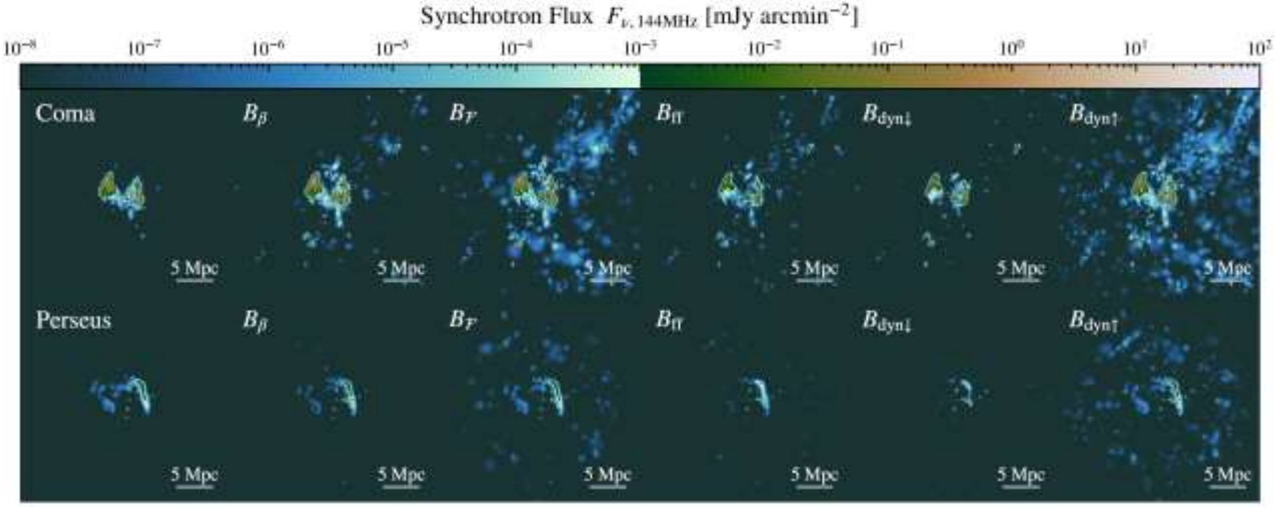
- 2x3072³ non radiative (MHD+CRs)

- Shocks
- SFR
- AGN

$$\underbrace{\frac{\partial f}{\partial t} + \mathbf{u}\cdot\nabla f}_{\text{spatial convection}} - \underbrace{\nabla\left(\boldsymbol{\kappa}\nabla f\right)}_{\text{spatial diffusion}} =$$

$$\underbrace{\frac{1}{3}\left(\nabla\cdot\mathbf{u}\right)p\frac{\partial f}{\partial p}}_{\text{momentum convection}} + \underbrace{\frac{1}{p^2}\frac{\partial}{\partial p}\left(p^2\left[b_\ell f + D_p\frac{\partial f}{\partial p}\right]\right)}_{\text{momentum diffusion + continuous losses}} - \underbrace{\frac{f(p,\mathbf{x},t)}{t_c(p,\mathbf{x})}}_{\text{catastrophic losses}} + \underbrace{j(p,\mathbf{x})}_{\text{source term}}$$

Coma:
-> extended radio emission!
Perseus:
-> only very central radio emission
Virgo:
-> no diffuse radio emission

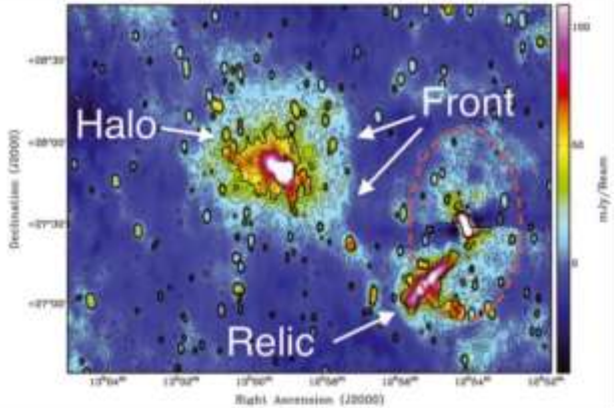


Predicted radio emission from turbulent re-acceleration for Coma, Perseus and Virgo very Promising!

Work in progress !

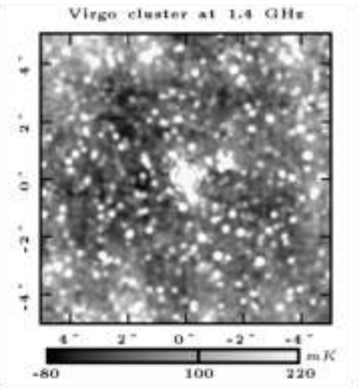
Diffuse radio emission in/around the Coma cluster: beyond simple accretion

Shea Brown and Lawrence Rudnick



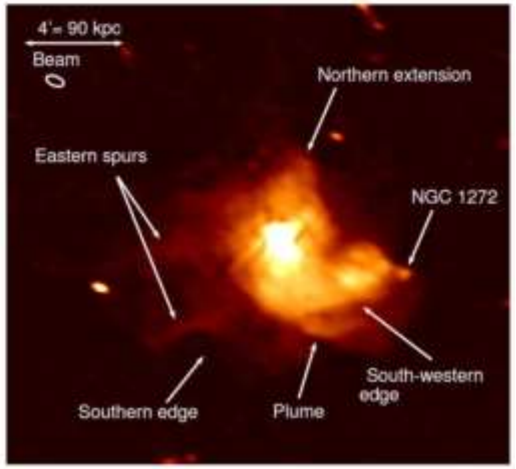
Astronomy & Astrophysics

Detection of a radio halo in the Virgo cluster



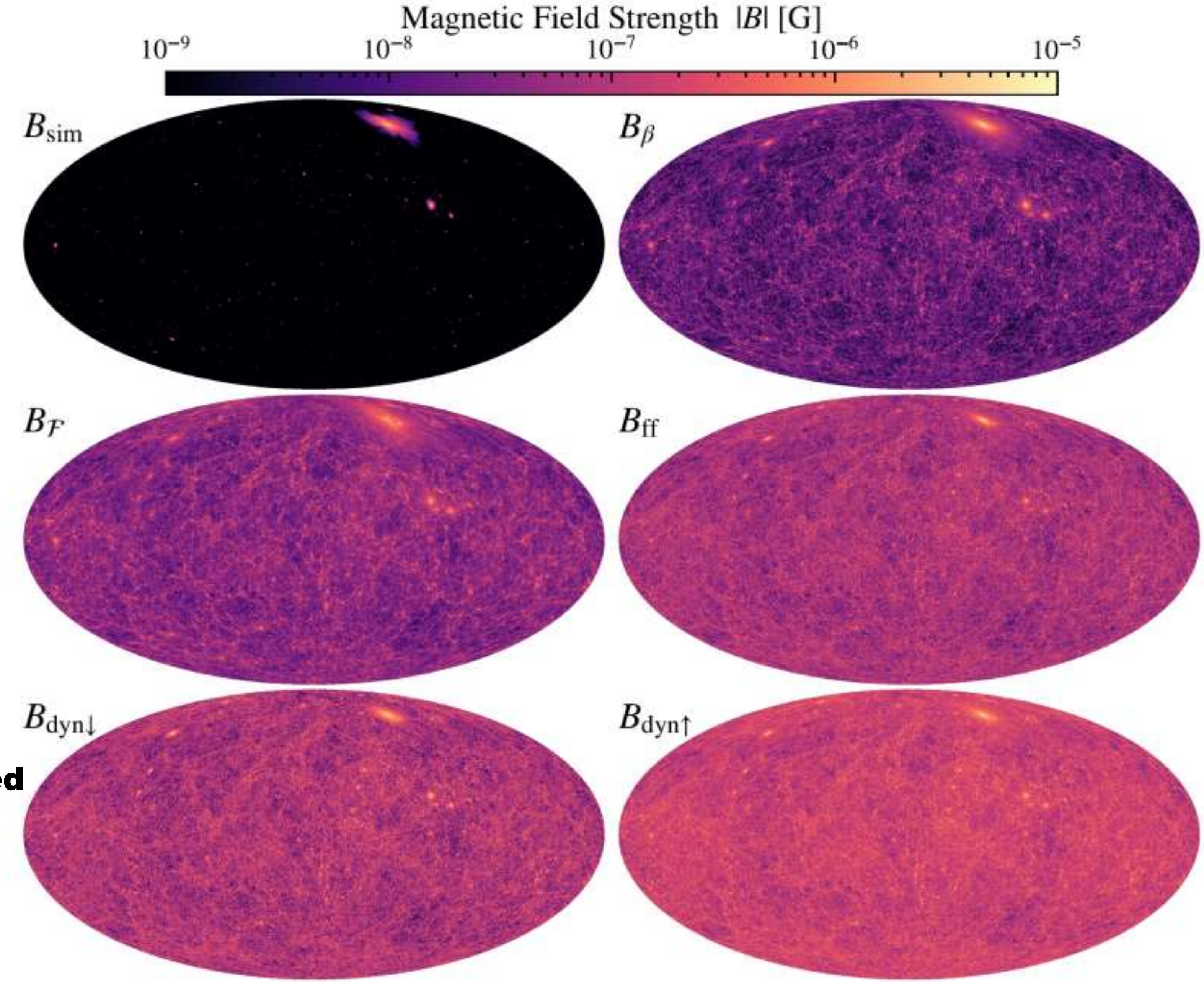
1. We do not detect a bright, large-scale radio halo, as is observed in the Coma cluster.
2. We detect a radio halo around the elliptical galaxy M 86 with an estimated radial extent of ~2° and an estimated total flux density of 5 ± 1.5 Jy.

JVLA Details the Structure of the Mini-Halo in the Perseus Cluster



Simulationg the LOcal Web (SLOW)

L. Böss



Primordial, simulation

B scaled as β = 50

B scaled with turbulent pressure

B scaled as frozen in

B scaled as saturated dynamo, with cut in voids

B scaled as saturated dynamo

Böss+ 2024

Simulationg the LOcal Web (SLOW)

L. Böss

Primordial, simulation

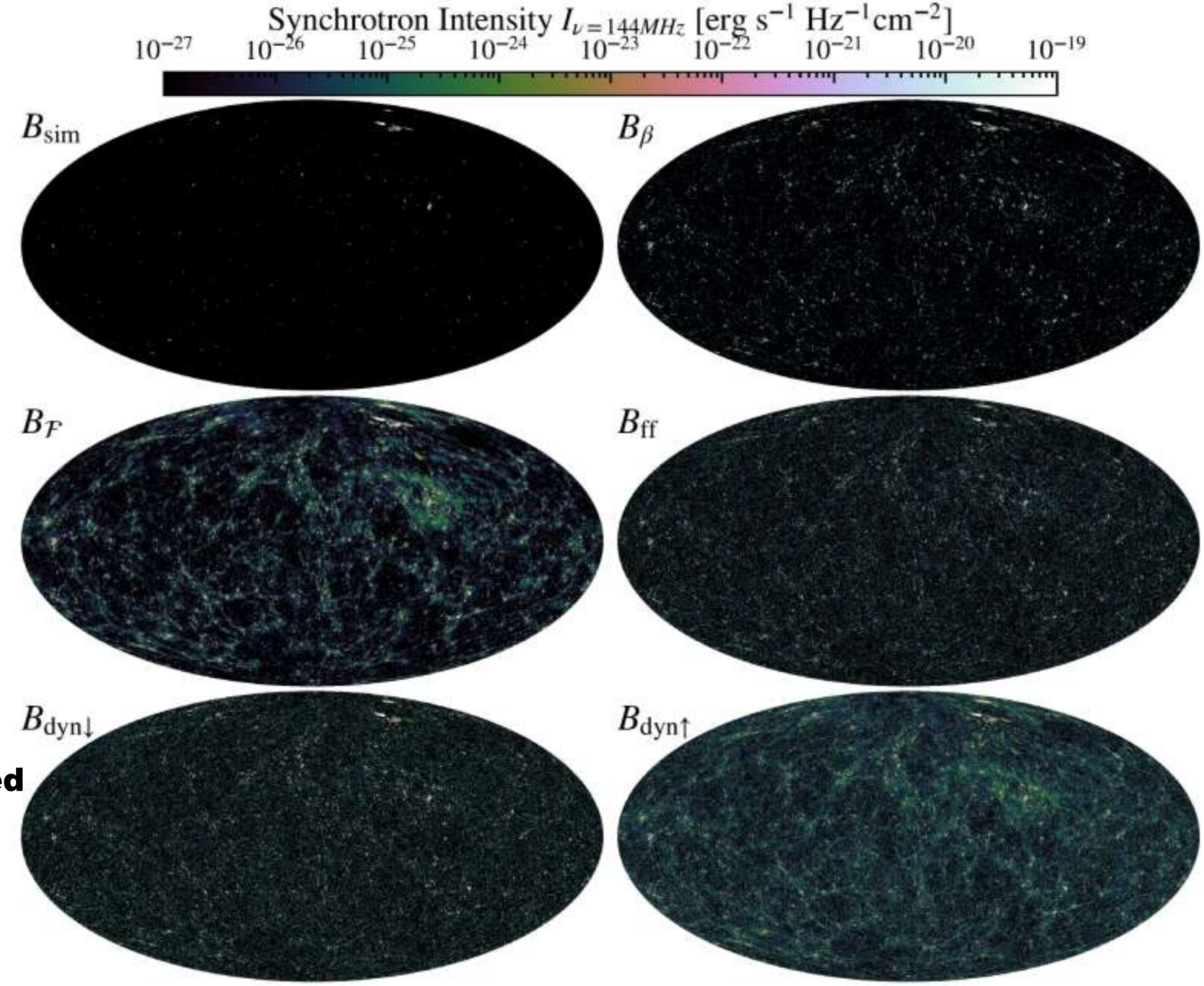
B scaled as $\beta = 50$

B scaled with turbulent pressure

B scaled as frozen in

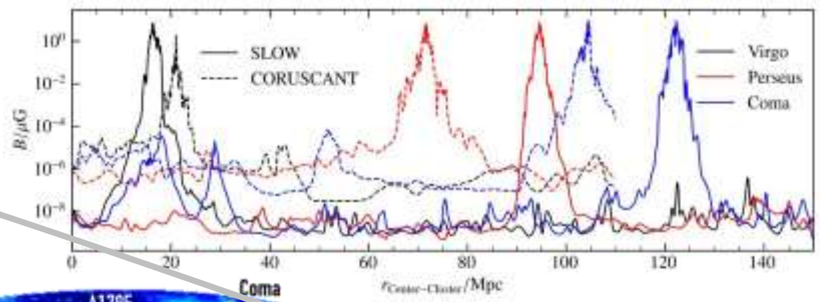
B scaled as saturated dynamo, with cut in voids

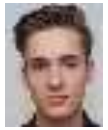
B scaled as saturated dynamo



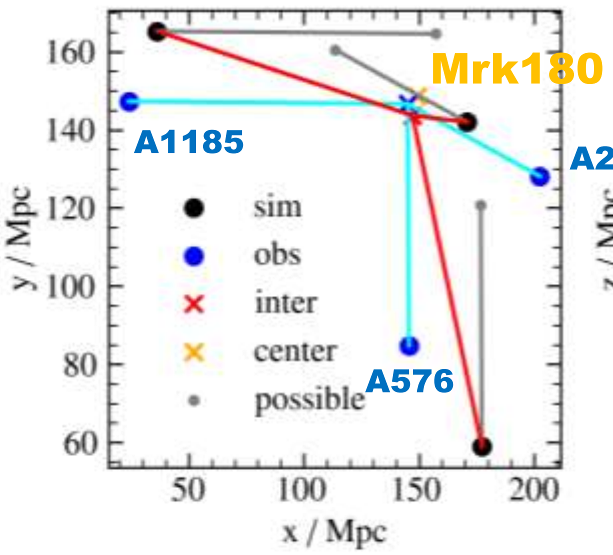
Böss+ 2024

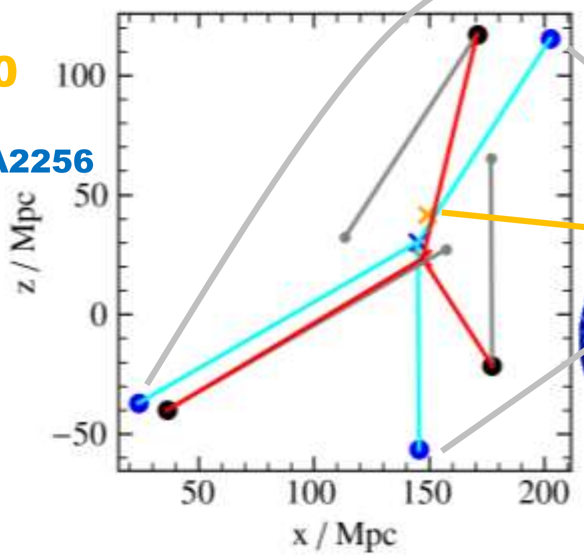
Simulationg the LOcal Web (SLOW)

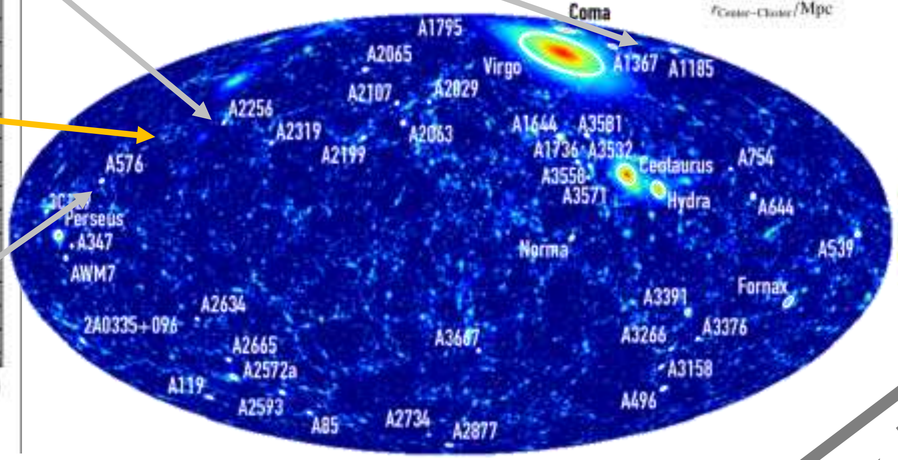




J. Stoiber



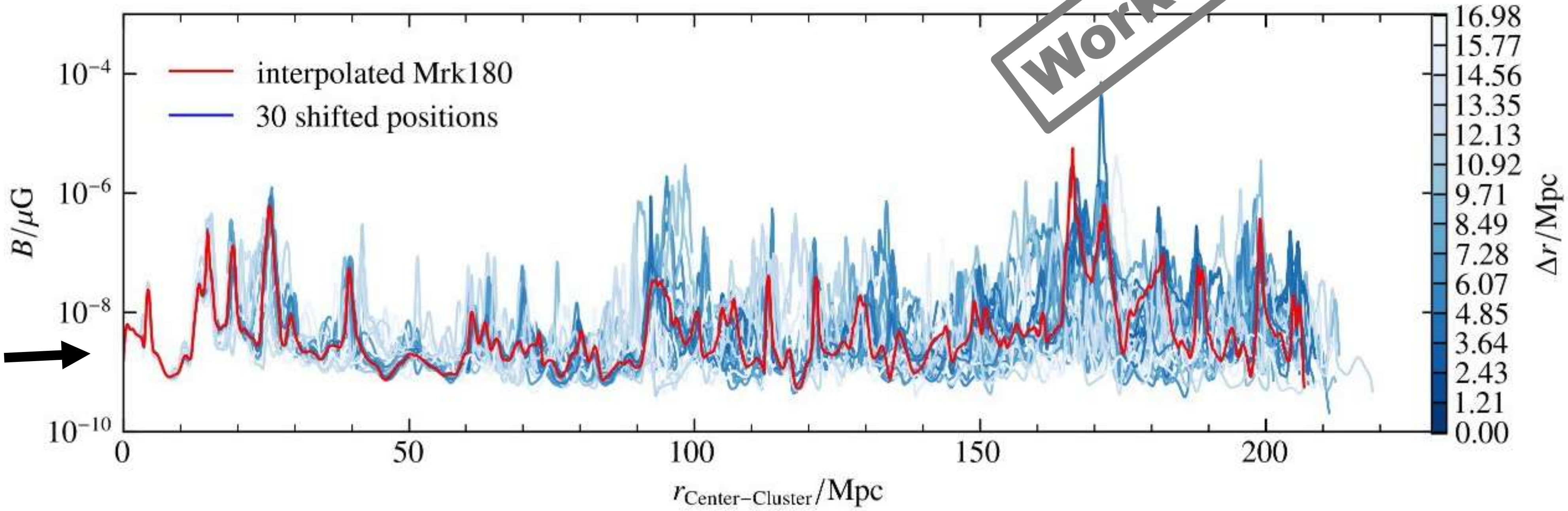




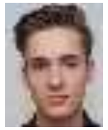
Work in progress !

Estimating uncertainty of positional error for the γ-ray source.

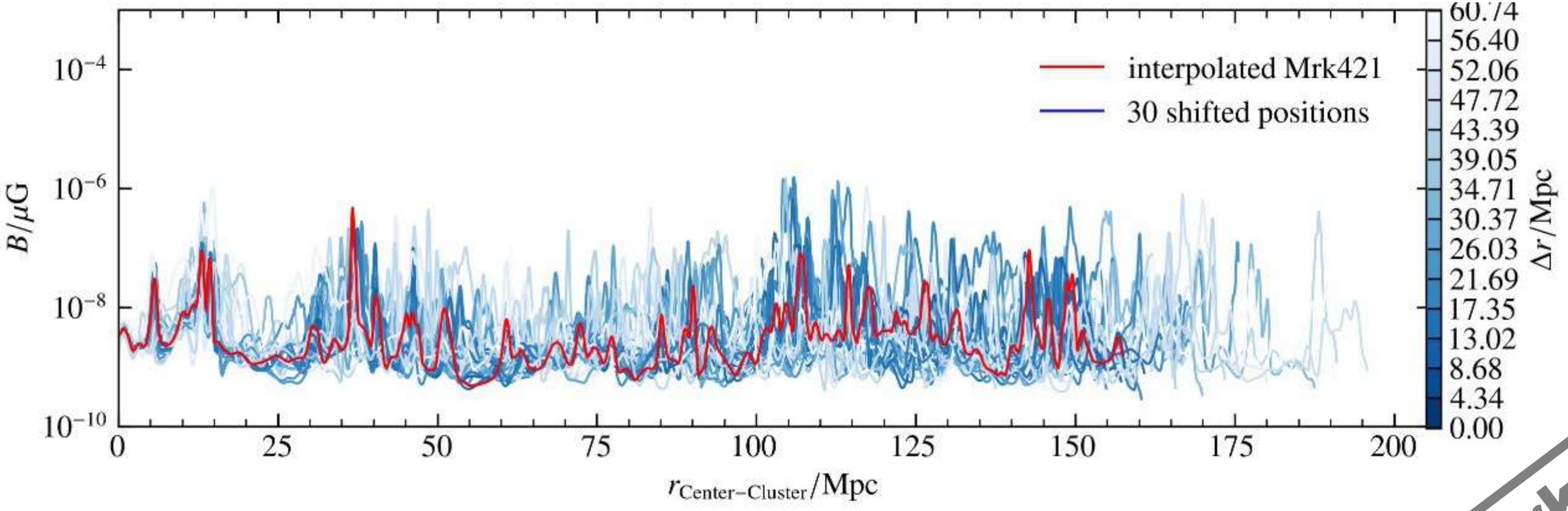
B-Field and its uncertainty for a sightline to the γ-ray source for one magnetic field model.

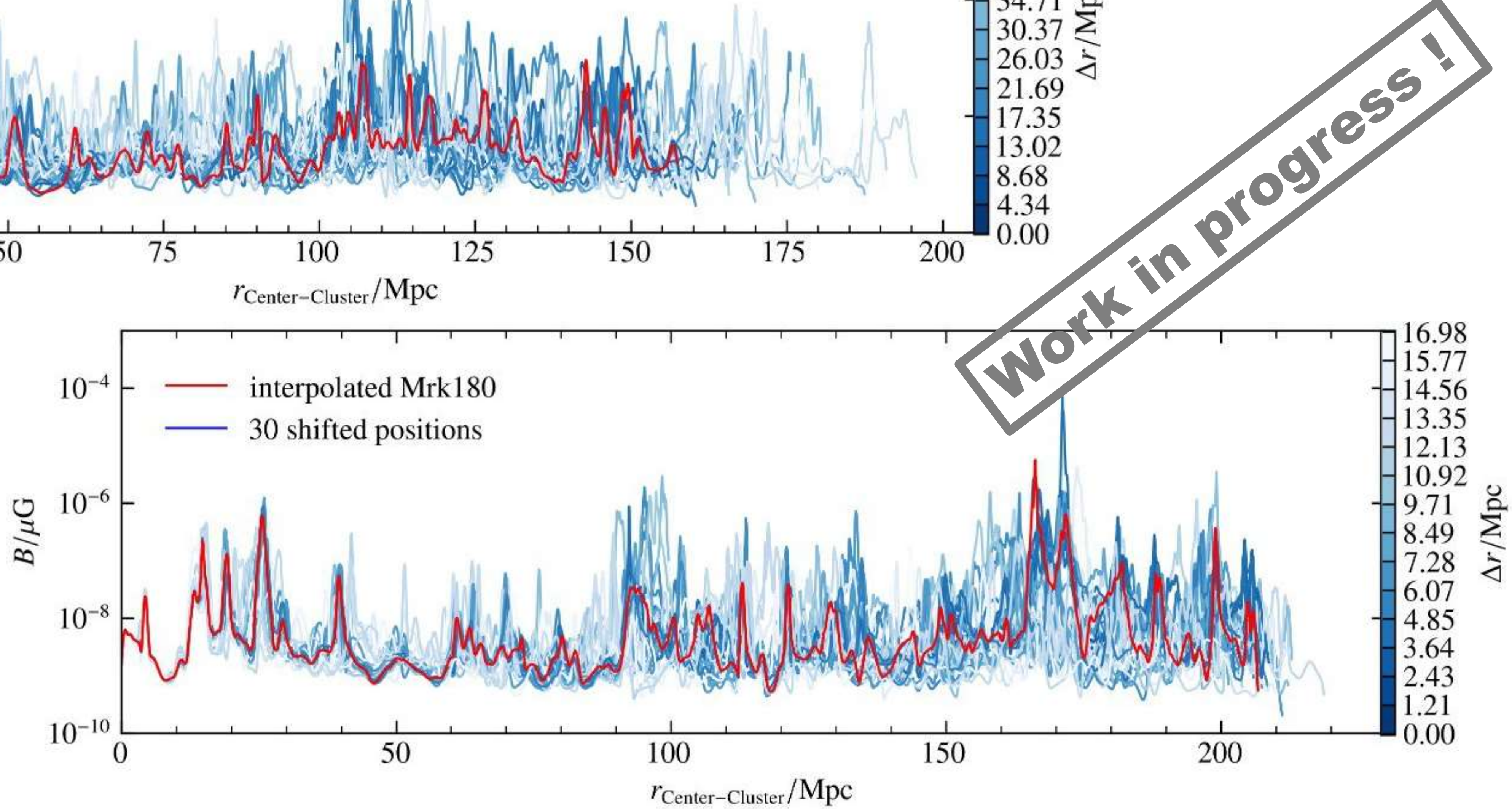


Simulationg the LOcal Web (SLOW)



J. Stoiber





Connecting to Galaxies

Radio shocks on galaxy scale ?

Discovery of a new extragalactic circular radio source with ASKAP: ORC J0102–2450

Bärbel S. Koribalski,[1,2]⋆ Ray P. Norris,[2,1] Heinz Andernach,[3] Lawrence Rudnick,[4] Stanislav Shabala,[5] Miroslav Filipović,[2] and Emil Lenc[1]

[1]*Australia Telescope National Facility, CSIRO Astronomy and Space Science, P.O. Box 76, Epping, NSW 1710, Australia*
[2]*School of Science, Western Sydney University, Locked Bag 1797, Penrith, NSW 2751, Australia*
[3]*Departmento de Astronomía, Universidad de Guanajuato, Callejón de Jalisco s/n, Guanajuato, C.P. 36023, GTO, Mexico*
[4]*Minnesota Institute for Astrophysics, University of Minnesota, 116 Church St. SE, Minneapolis, MN 55455, USA*
[5]*School of Natural Sciences, University of Tasmania, Private Bag 37, Hobart 7001, Australia*

Koribalski+ 2022

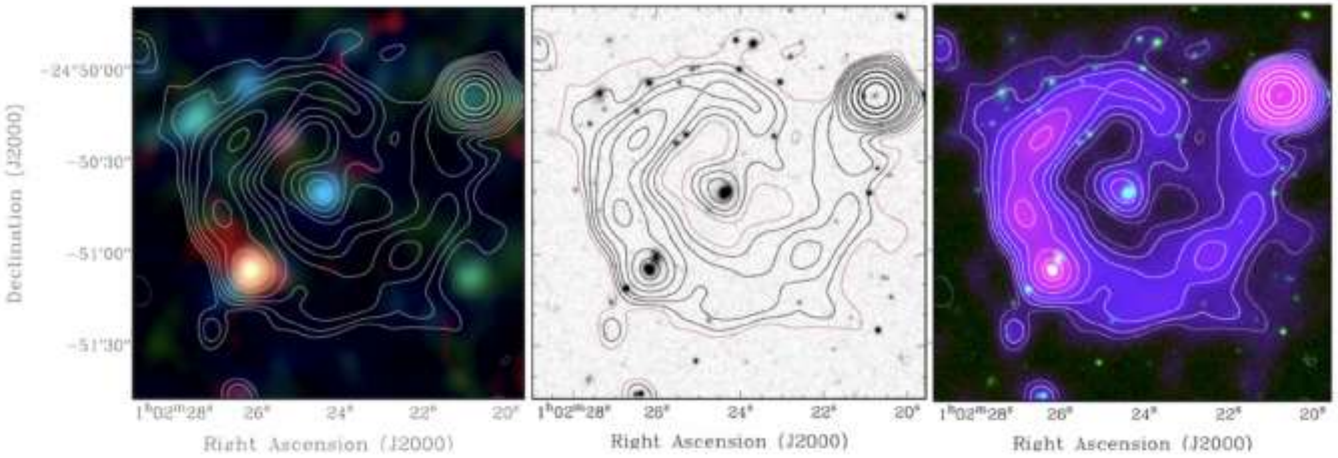


Figure 2. ASKAP radio continuum contours of ORC J0102–2450 overlaid onto a WISE RGB colour image (red: 12μm (W3), green: 4.6μm (W2), and 3.4μm (W1))

source name		discovery telescope	central host galaxy	galaxy redshift	ring diameter [arcsec]	ring diameter [kpc]	spectral index	Ref.
ORC J2103–6200	(ORC 1)	ASKAP	WISE J210258.15–620014.4	0.55	80	510	-1.17 ± 0.04	Norris et al. 2021a
ORC J1555+2726	(ORC 4)	GMRT	WISE J155524.65+272633.7	0.39	70	370	-0.92 ± 0.18	Norris et al. 2021a
ORC J0102–2450	(ORC 5)	ASKAP	DES J010224.33–245039.5	0.27	70	300	-0.8 ± 0.2	this paper

Ring like features beyond R_{vir} (300 kpc – 500 kpc) in several (5) galaxies found!

Suggested to be AGN or star-burst winds, but could be just merger shocks ?

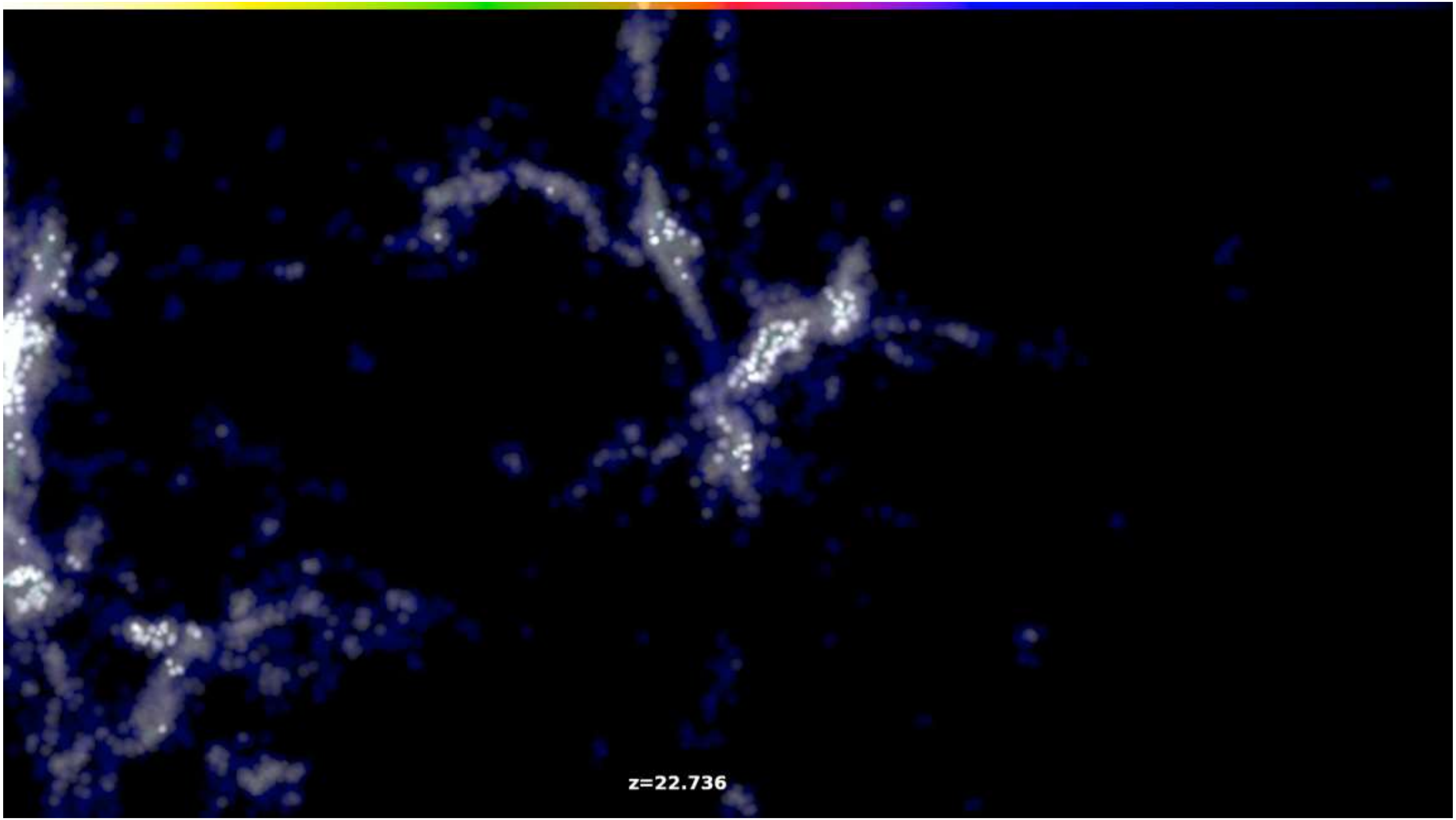
ORC centre galaxies

(from DES DR9 via the *legacyserver.org/viewer* – not to scale)

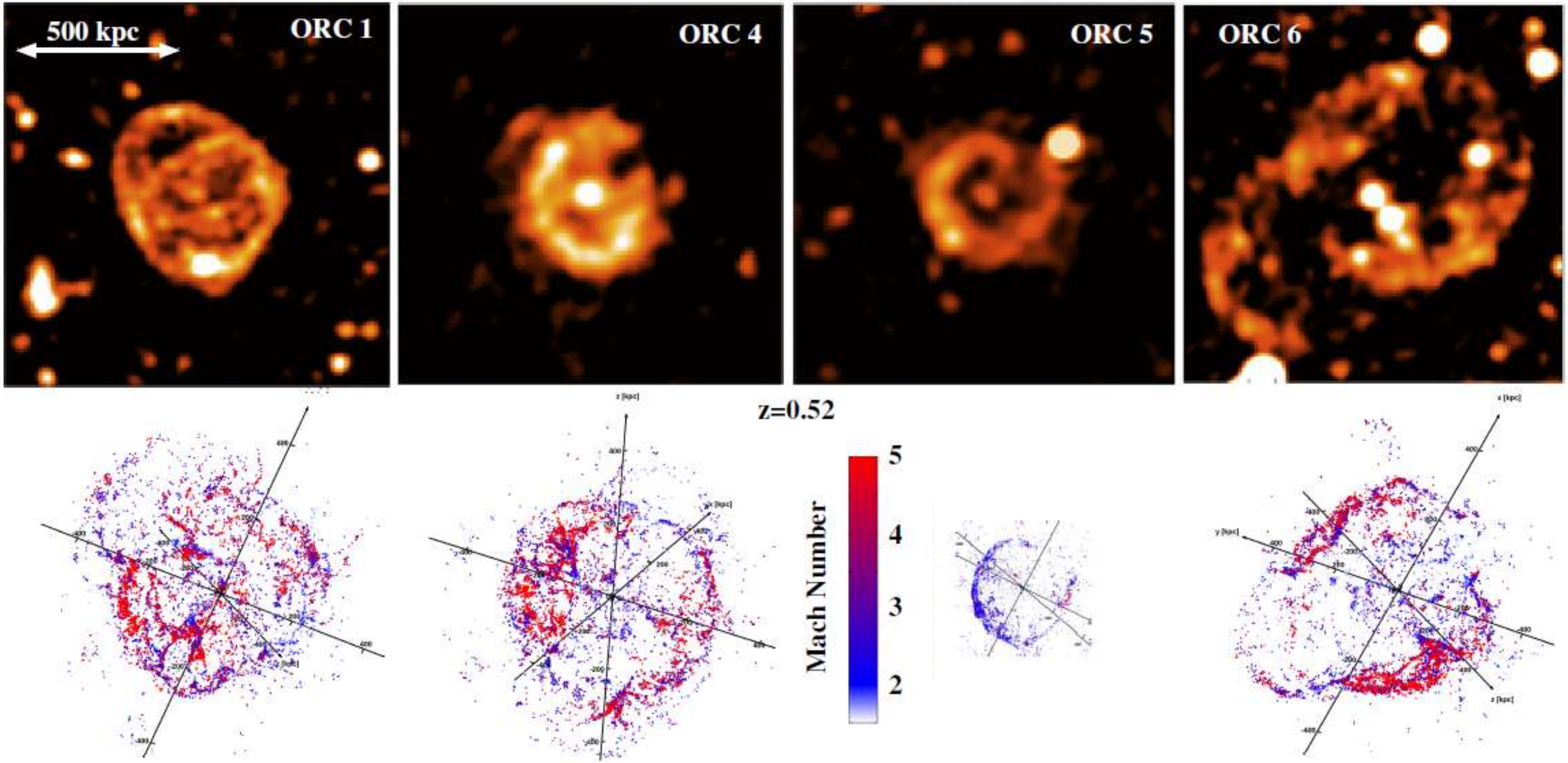
ORC 1 ORC 4 ORC 5

$M_* \sim 10^{11}\ M_{sol}$

Shocks in the simulated galaxy

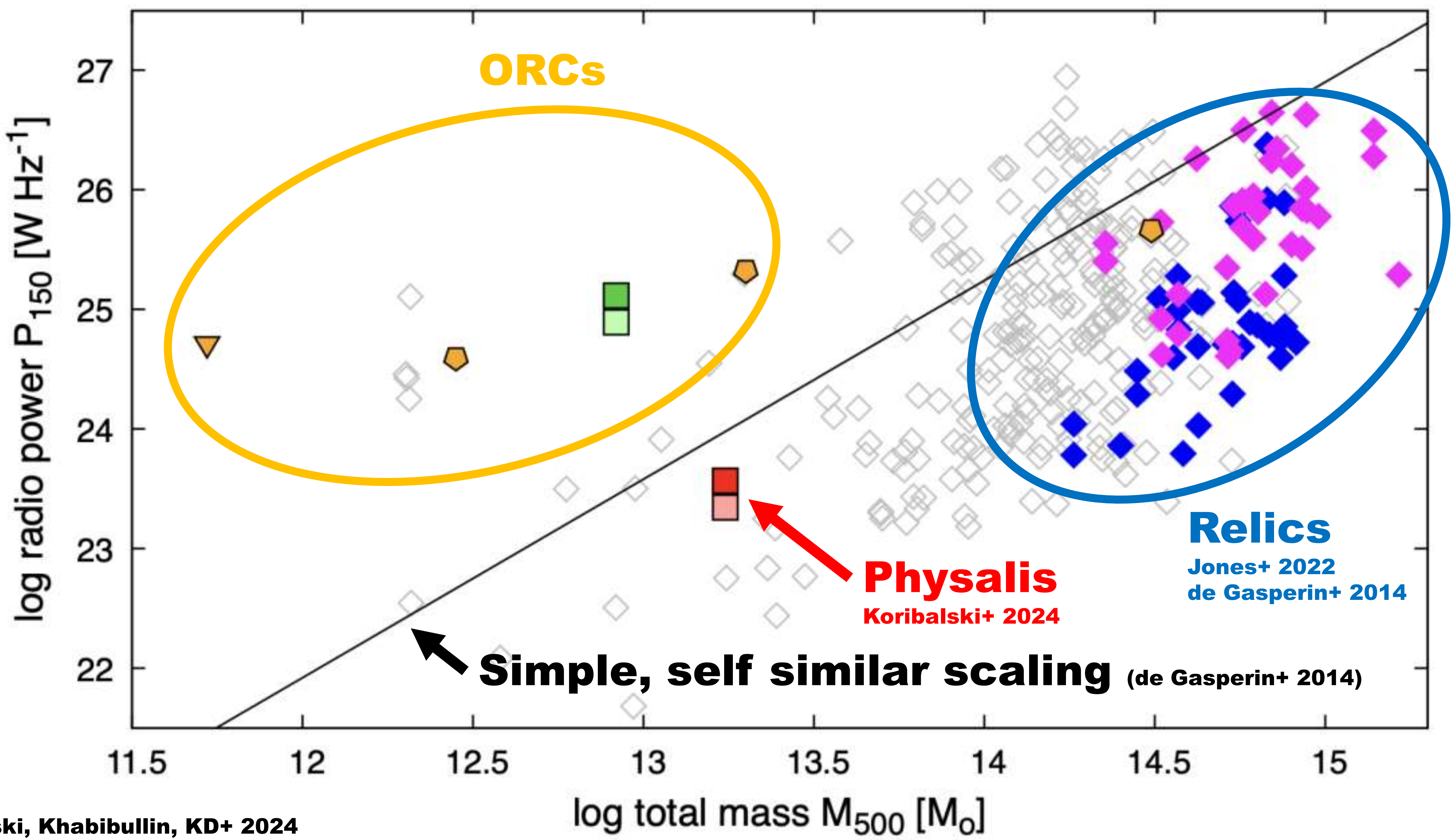


Shock structures are matching the observed ORCs



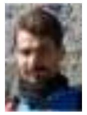
KD+ 2022

Shock structures linking galaxy clusters to galaxies



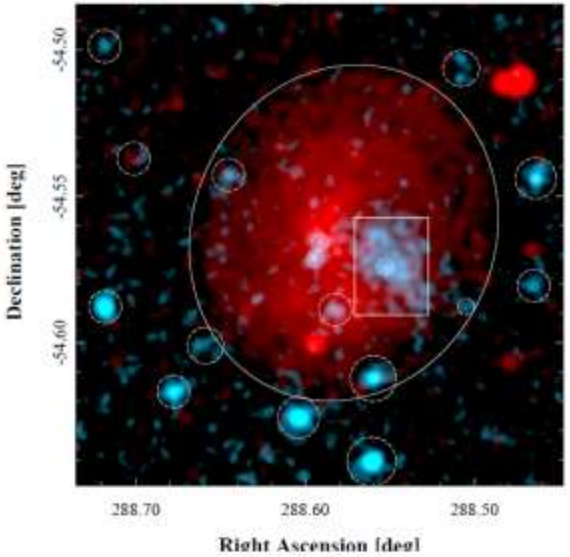
Koribalski, Khabibullin, KD+ 2024

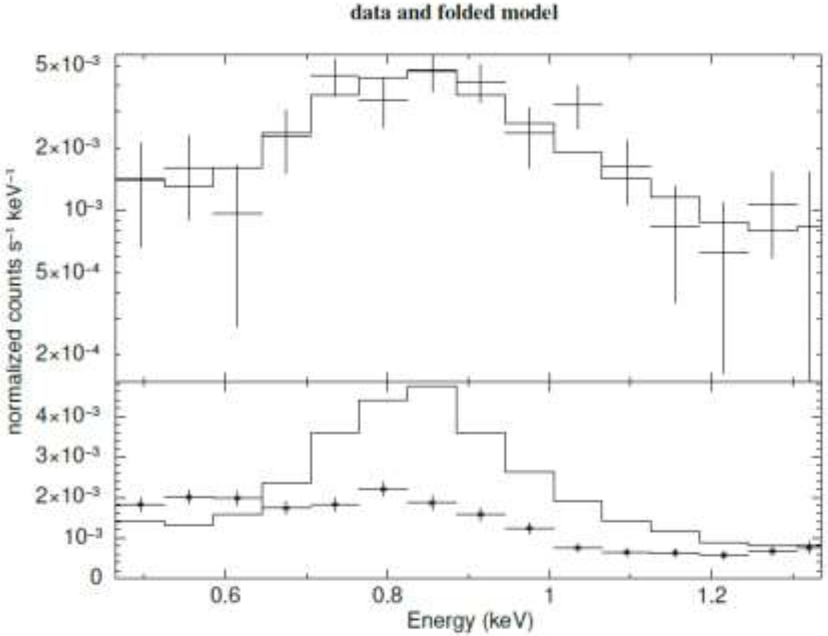
The Physalis system, an early stage of an ORC?



I. Khabibullin

ASKAP / XMM





ESO 184-G042 and LEDA 418116

D = 75 Mpc (z = 0.017)

log stellar mass [$M_\odot$] ~ 11.1 and 10.7

$P_{th} \approx 3\times10^{-12}$ erg cm^{-3}

$E_{tot} \sim 2 \times 10^{59}$ erg ← **Energy involved**

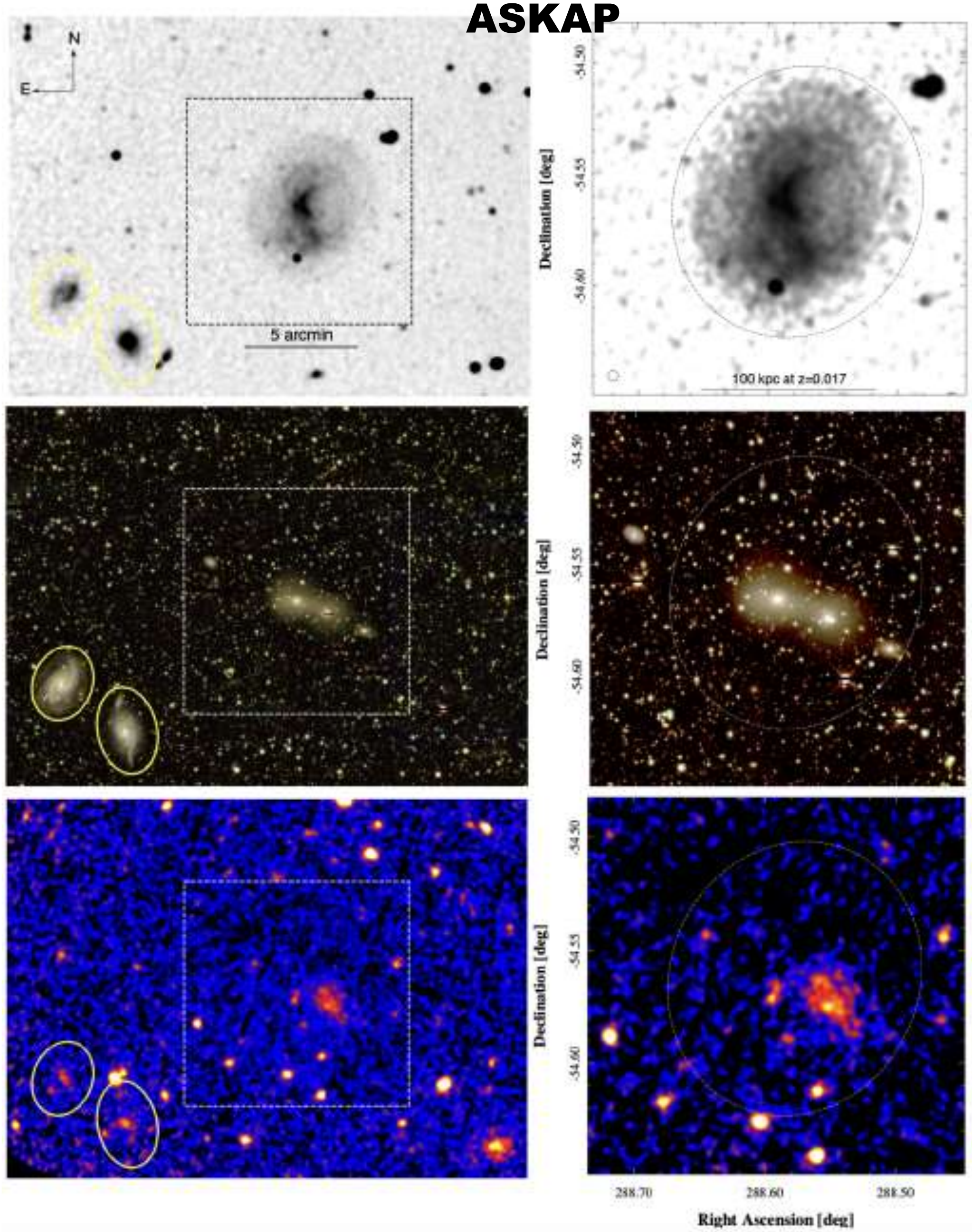
$t_{cool} \sim 4 \times 10^{8}$ yr ← **Timescale involved**

Similar than in clusters, radio plasma is anti-correlated with thermal plasma (but reversed!).

ASKAP

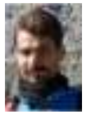
DESI

XMM



Koribalski, Khabibullin, KD+ 2024

The Physalis system in simulations?



I. Khabibullin

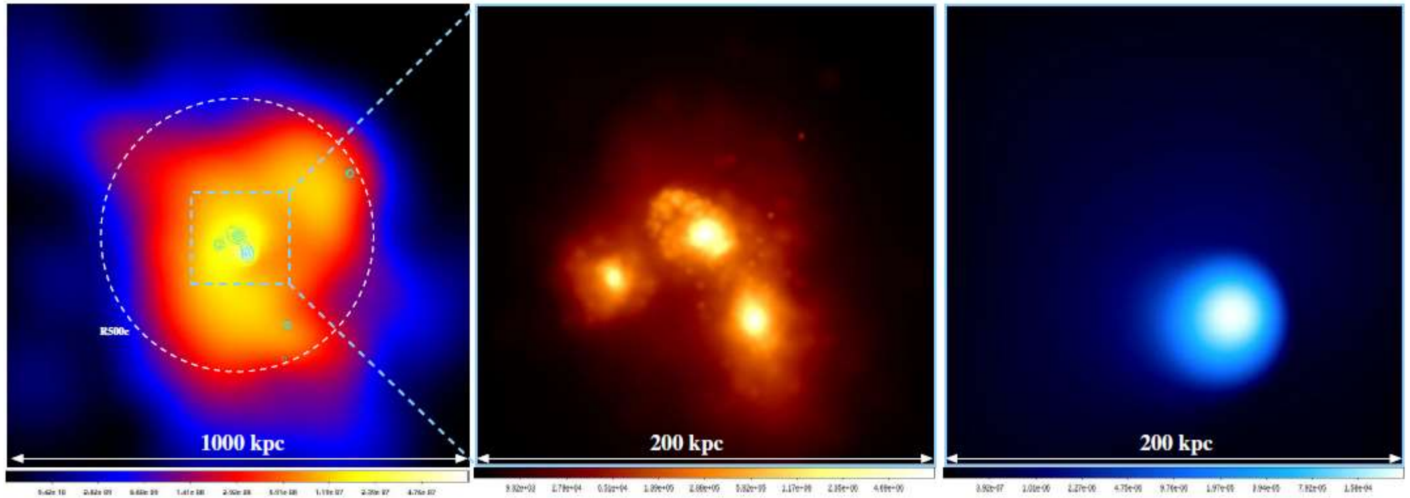
Magneticum Box2b/hr (640 h^{-1}cMpc)
$10^{13} < M_{vir} < 3x10^{13}$
-> ~26000 haloes

Forcing two massive galaxies with D < 70kpc and more hot gas associated to the galaxy with the lower stellar mass

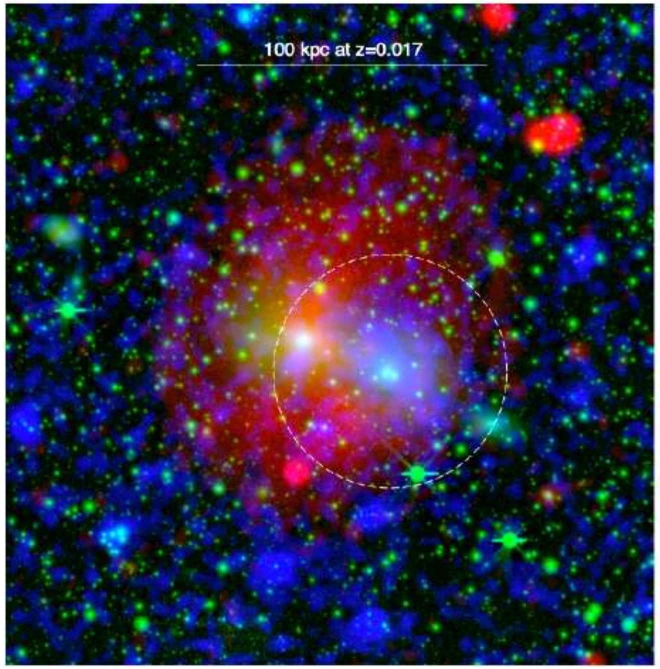
-> 10 Haloes

Closer inspection, only 1 Halo shows a good match:

SZ **K-Band** **X-ray**



ASKAP / XMM / DESI



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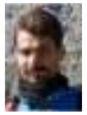
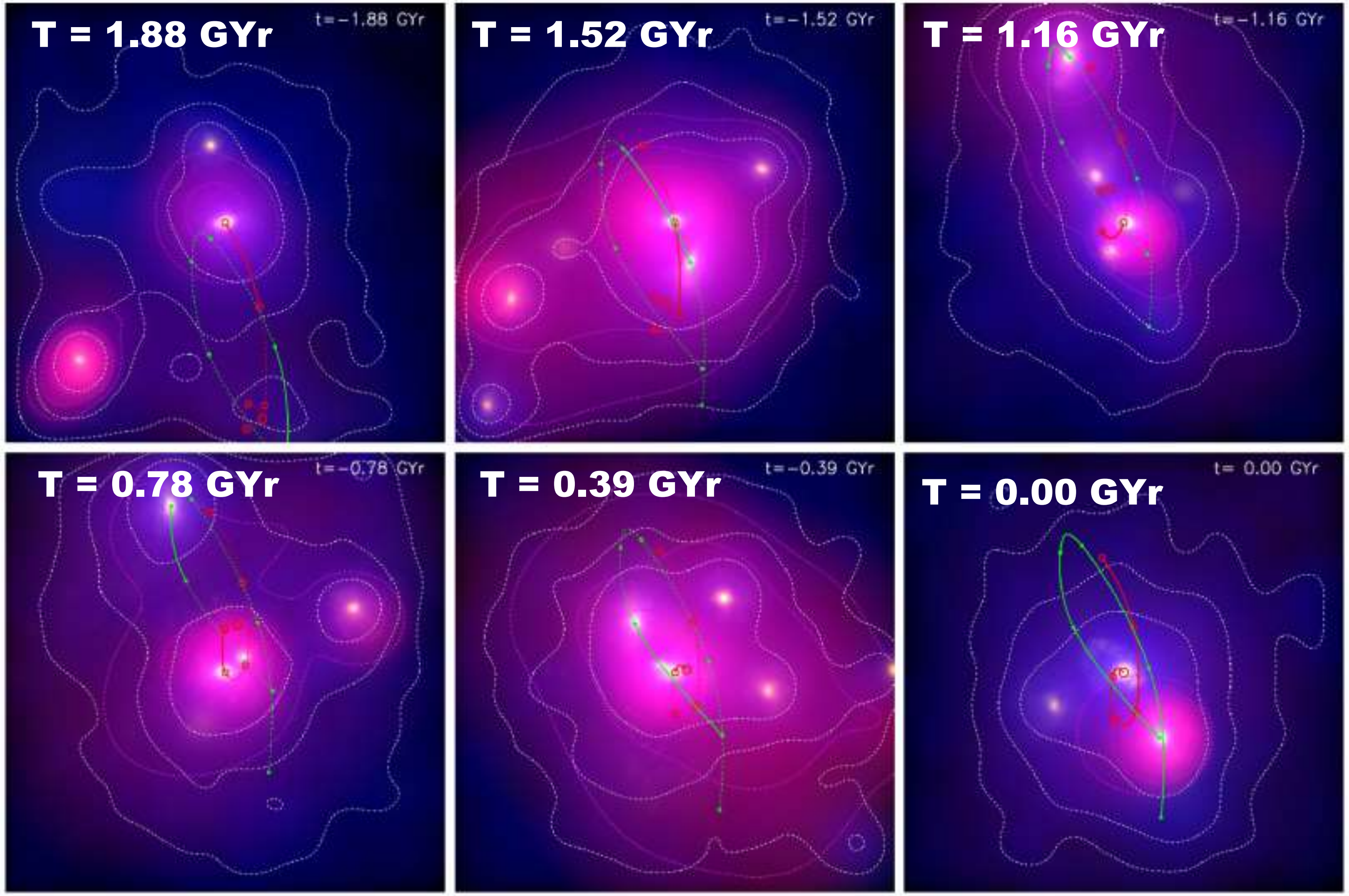
Koribalski, Khabibullin, KD+ 2024

The Physalis system, what to learn from it?



I. Khabibullin

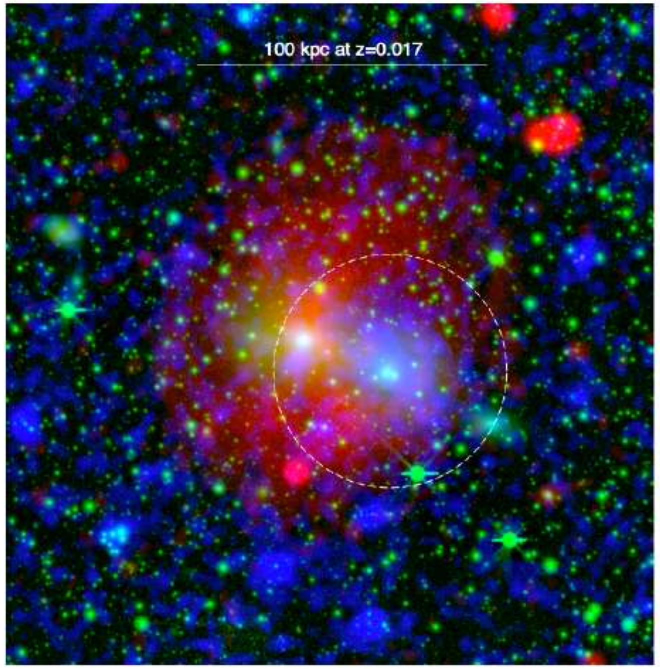


DM (blue)

X-ray (red)

SDSS-K (white)

ASKAP / XMM / DESI



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In the last 0.49 GYr the BH grows (by accretion) significantly ~$10^8 M_\odot$, releasing an energy of 10^{59} erg and displaces the IGrM from the radio emitting region showing that AGN and shocks could produce ORCs!

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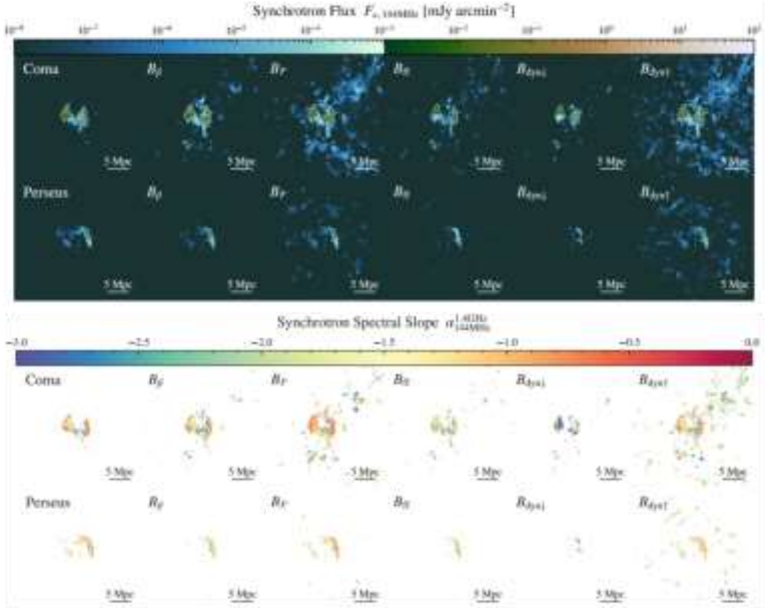
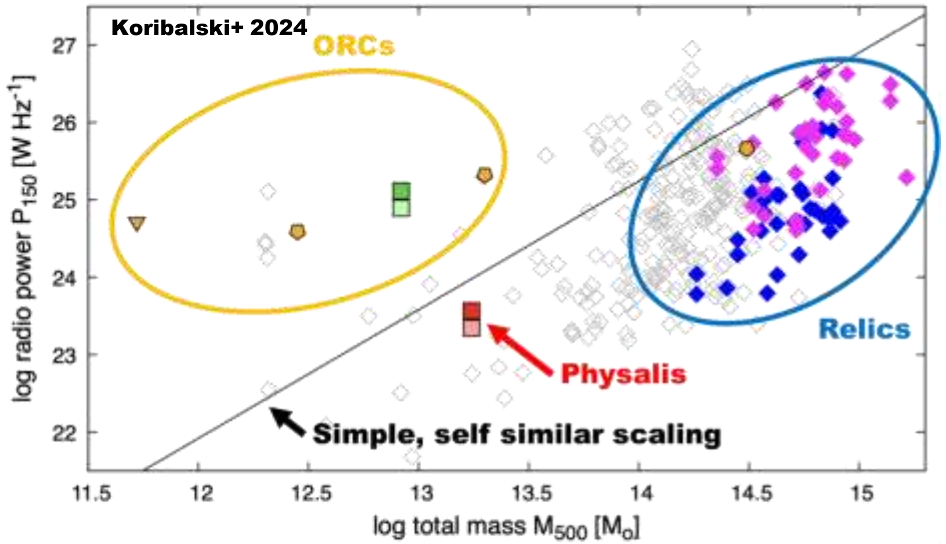
Conclusions

Plasma Physics is a key element for proper modeling of the thermal and non thermal properties within the ICM in galaxy clusters !

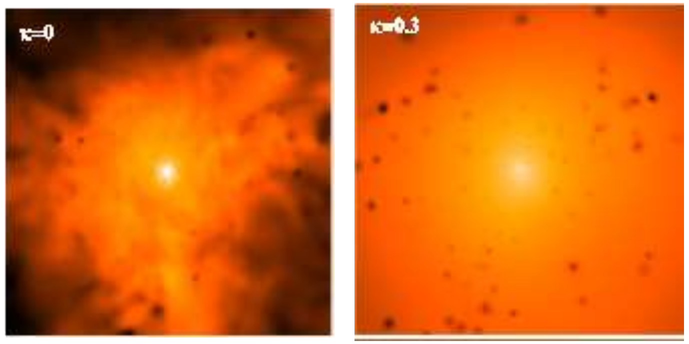
Bridging galaxies to galaxy clusters give new insights how non-thermal emission is linked to structure formation and might challenge Plasma Physics!



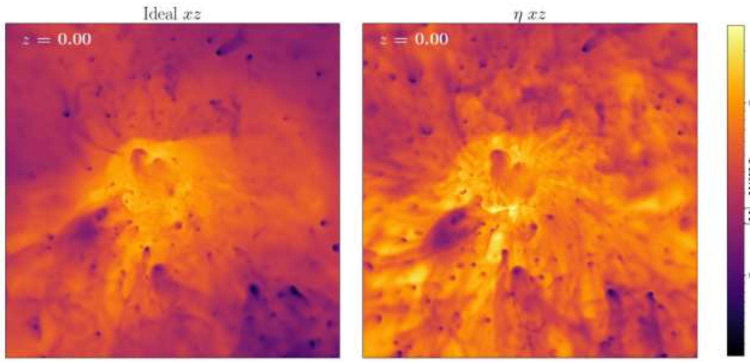
Böss+ 2024



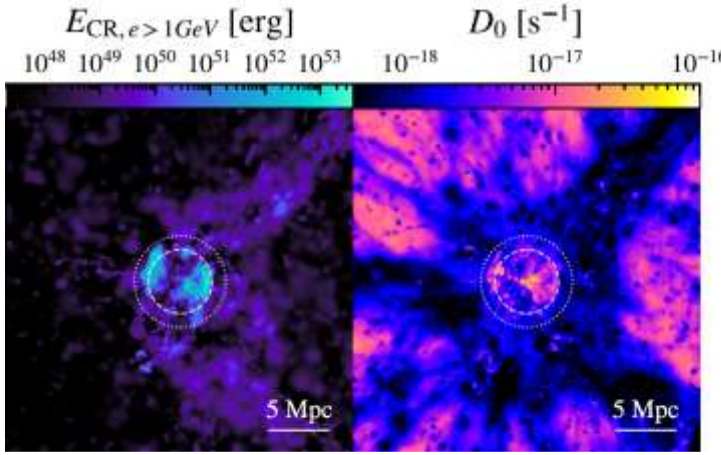
Heat transport



Viscosity



CR acceleration



Current generation of constrained simulations allow to obtain unique insights into the local structures.

- ➢ **First steps to make the Local Universe a Plasma Physics lab!**