Uniqueness of galaxy groups in the structural hierarchy from its radio signature

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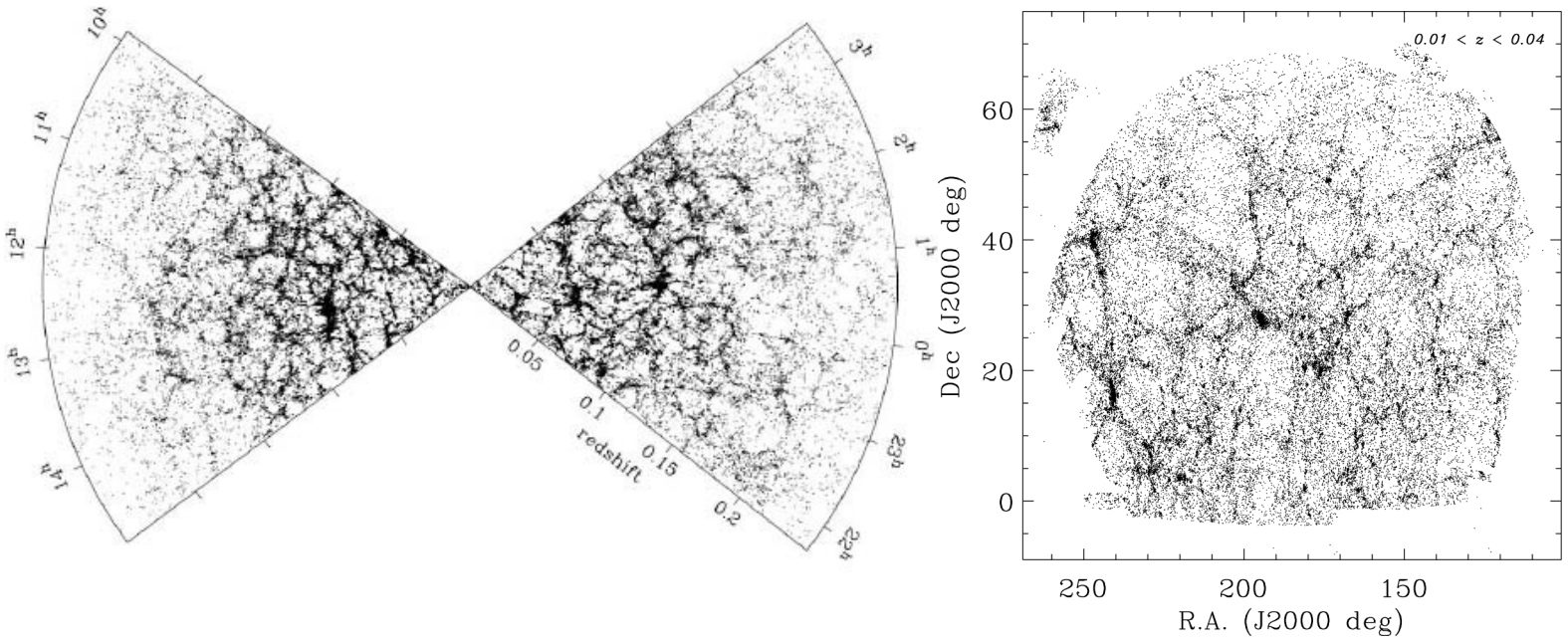
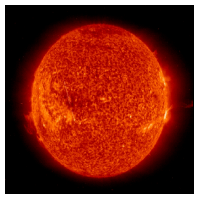
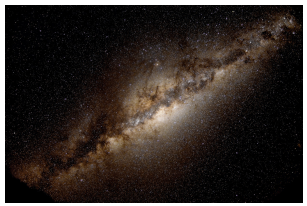
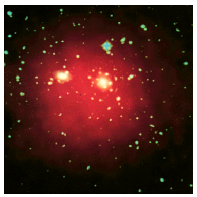
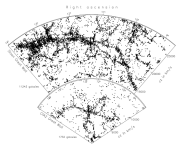
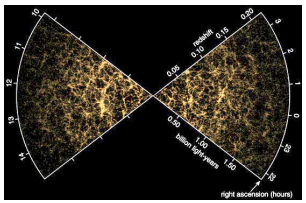
Plan of this talk



Panel 1: Distribution of Galaxies in RA vs Redshift plot as observed in 2dF survey. **Panel 2:** Galaxy distribution within a sky patch of 100° by 60° and redshift span of 0.01 to 0.04 as seen in SDSS, Blanton et al. (2005)

- Structures are scattered but in a pattern indicating presence of filamentary networks, galaxy groups within the filaments and nodes and higher concentration at the cross roads of filaments forms galaxy clusters
- Component of LSS are: (i) Galaxies (ii) Group of Galaxies (iii) Filaments (iv) Galaxy clusters and (v) Super Clusters

Structural hierarchy

Star (Sun)	Star Clusters	Galaxy	groups?	Clusters of Galaxies	Super Cluster	Universe
			?			
Mass: $\sim 10^{30} kg$	$\sim 10^{4\ to\ 5} M_\odot$	$\sim 10^{11} M_\odot$	?	$\sim 10^{15} M_\odot$	$\sim 10^{17} M_\odot$	$\sim 10^{25} M_\odot$
Size: 12,442 km	$1.39 \times 10^6 km$	few 10s of parsec	?	1-10 Mpc	$\sim$ 100s of Mpc	$\sim$ 30 Gpc

- The mass accretion rate, $R_{\rm mass}\,(M,t) \equiv dM/dt$ of halos with mass M defined as

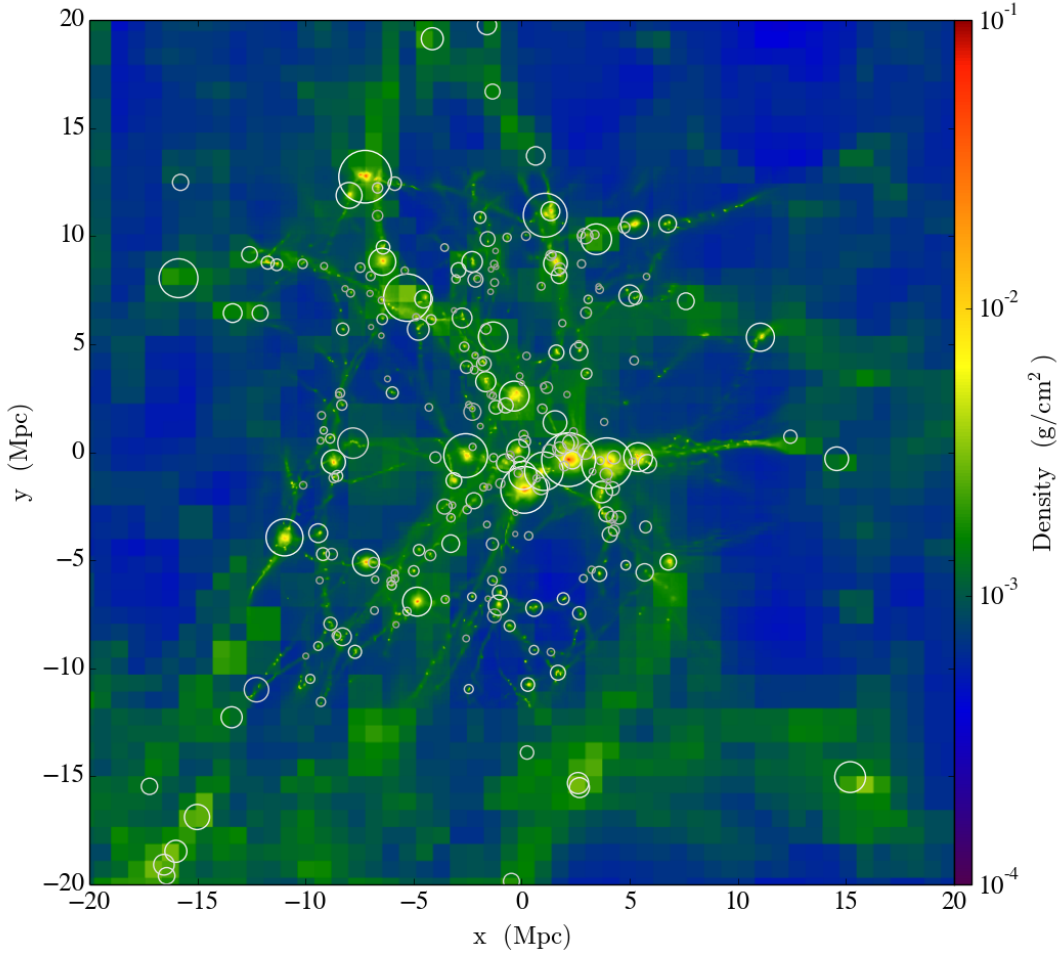
$$R_{\rm mass}\,(M,t) \;=\; \int_{M}^{M(1+\Delta_{\rm m})} \delta M r^{m}_{\rm LC}\left(M \;\rightarrow\; M^{'},t\right) dM^{'} \qquad (1)$$

  Where, $r^{m}_{\rm LC}$ is the rate of merging for a cluster formation process where $M^{'} > M$. If the ratio $\delta M/M << \Delta_{\rm m}$. [Salvador-Sole et al. (1998)]
  Rate is computed to be $\sim\ 10^4\ M_{\odot}$ [C. De Boni et al. 2015, A. Diaferio 2015] considering continuous accretion that corroborates ΛCDM model. But, with this rate, forming a cluster of Mass $10^{15}\ M_{\odot}$ will take 100 Gyr, i.e. more than the age of the universe.
- X-ray luminosity of galaxies averaged at 10^{39} erg s^{-1}. But, galaxy clusters of Mass few times $10^{14}\ M_{\odot}$ are having X-ray luminosity averaged at 10^{44} erg s^{-1} (C.L. Sarazin, Cambridge University Press, 1988). No way the accumulation of even $\sim$ 1000 of Galaxies can explain this.

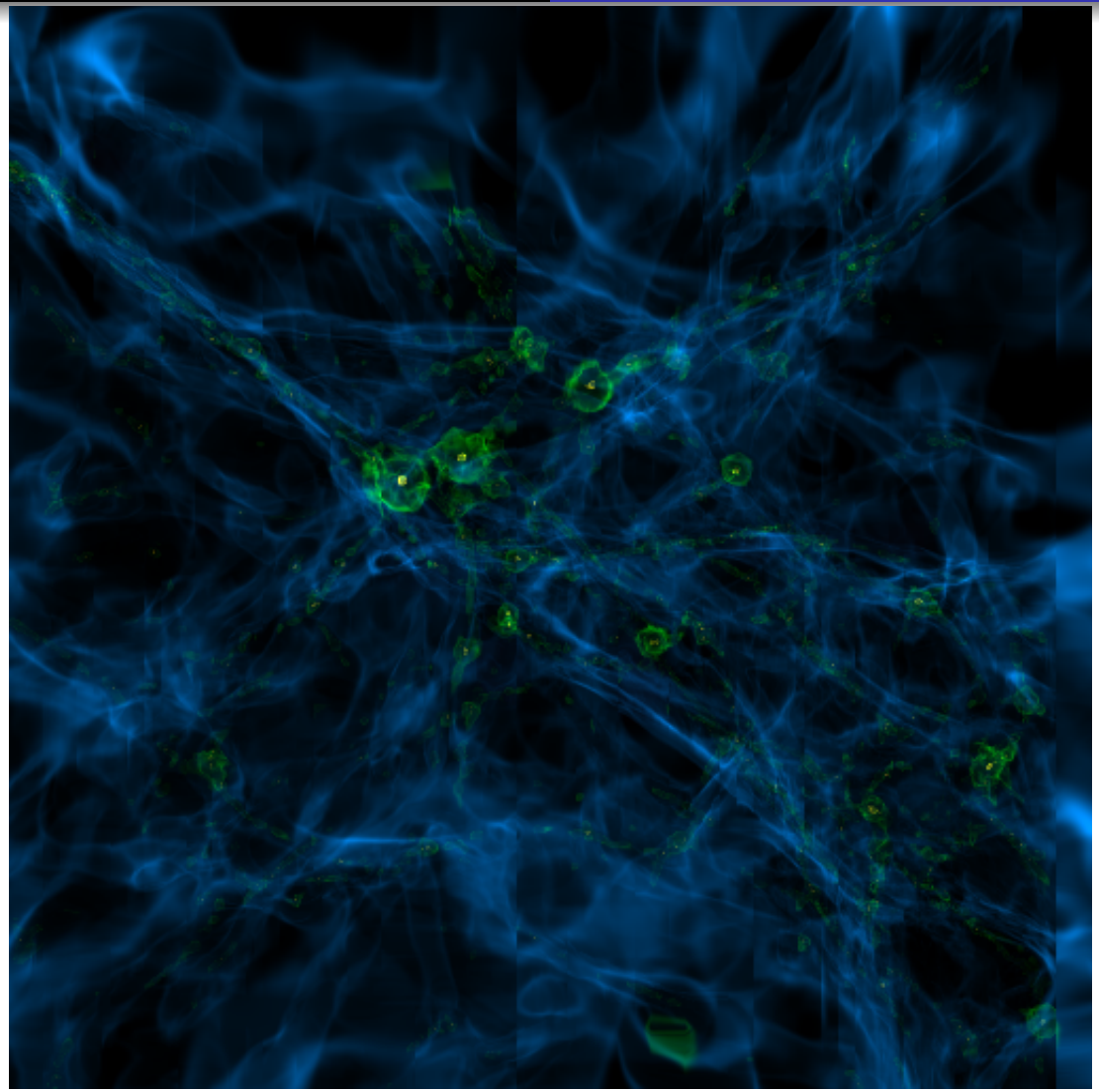
- To study the galaxy cluster formation with baryons we have used ENZO, a grid-based AMR hydrodynamic + N-body code

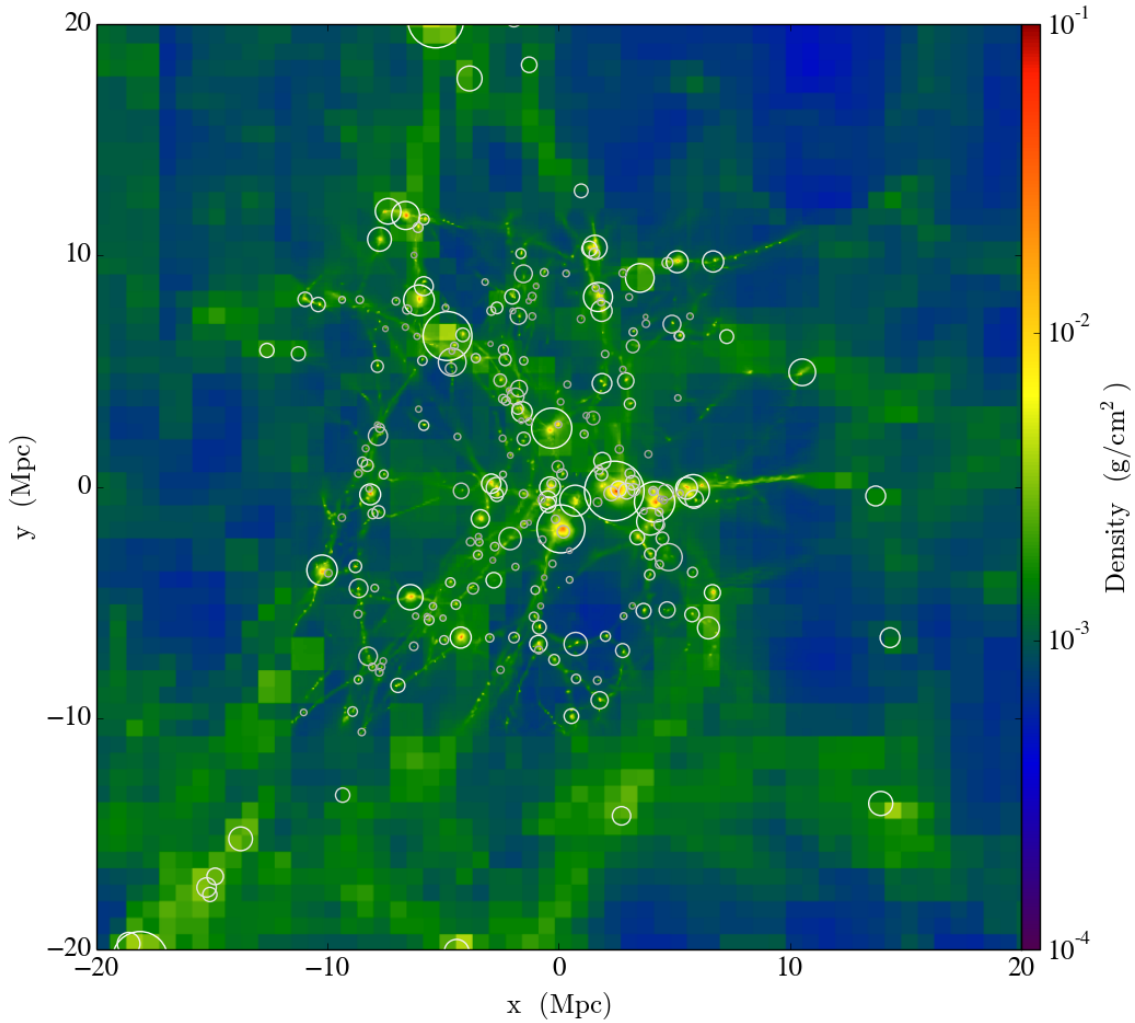
1. Dark matter - Dark matter and DM-baryon interactions are governed by gravitational force only. (N-body dynamics)
2. Baryons are effected by both gravitation and hydrodynamic laws (N-body + Euler's equations)
3. Heating and Radiative Cooling is used from Sarazin & White, 1987
4. We consider a cold dark matter dominated universe

Groups and clusters from the simulations

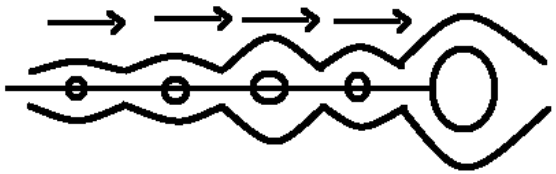


Galaxy groups and clusters from hydrodynamic simulations. An area of 40 Mpc^2 [S. Paul et al. 2015]

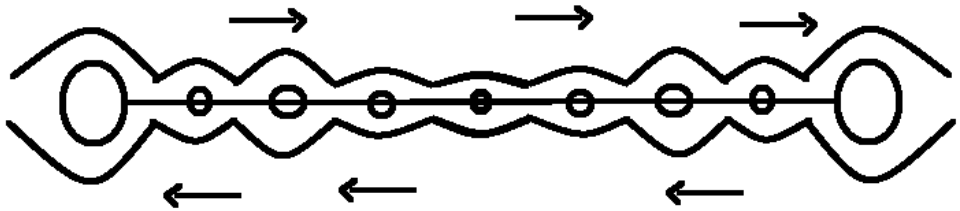



20
10
0
−10
−20
y (Mpc)
−20
−10
0
10
20
x (Mpc)
10^{-1}
10^{-2}
10^{-3}
10^{-4}
Density (g/cm^2)

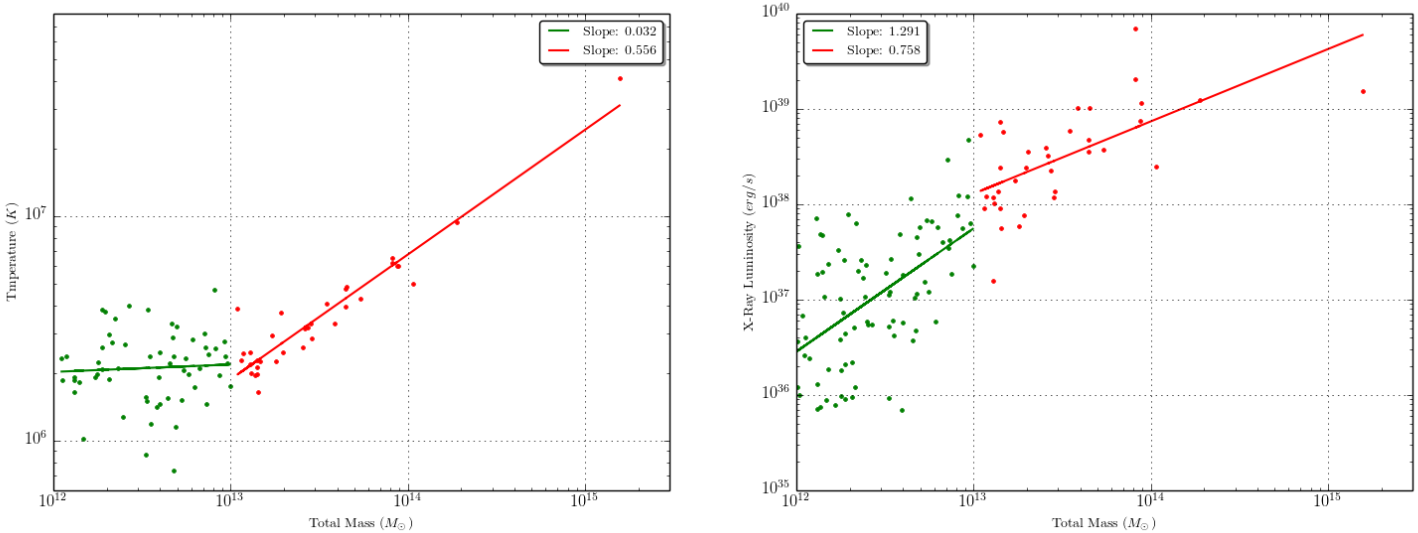
Knots (Galaxy groups) pushing material and DM halo to wards the clusters



Knots (Galaxy groups) may push or pull material and DM halo towards or away from the clusters



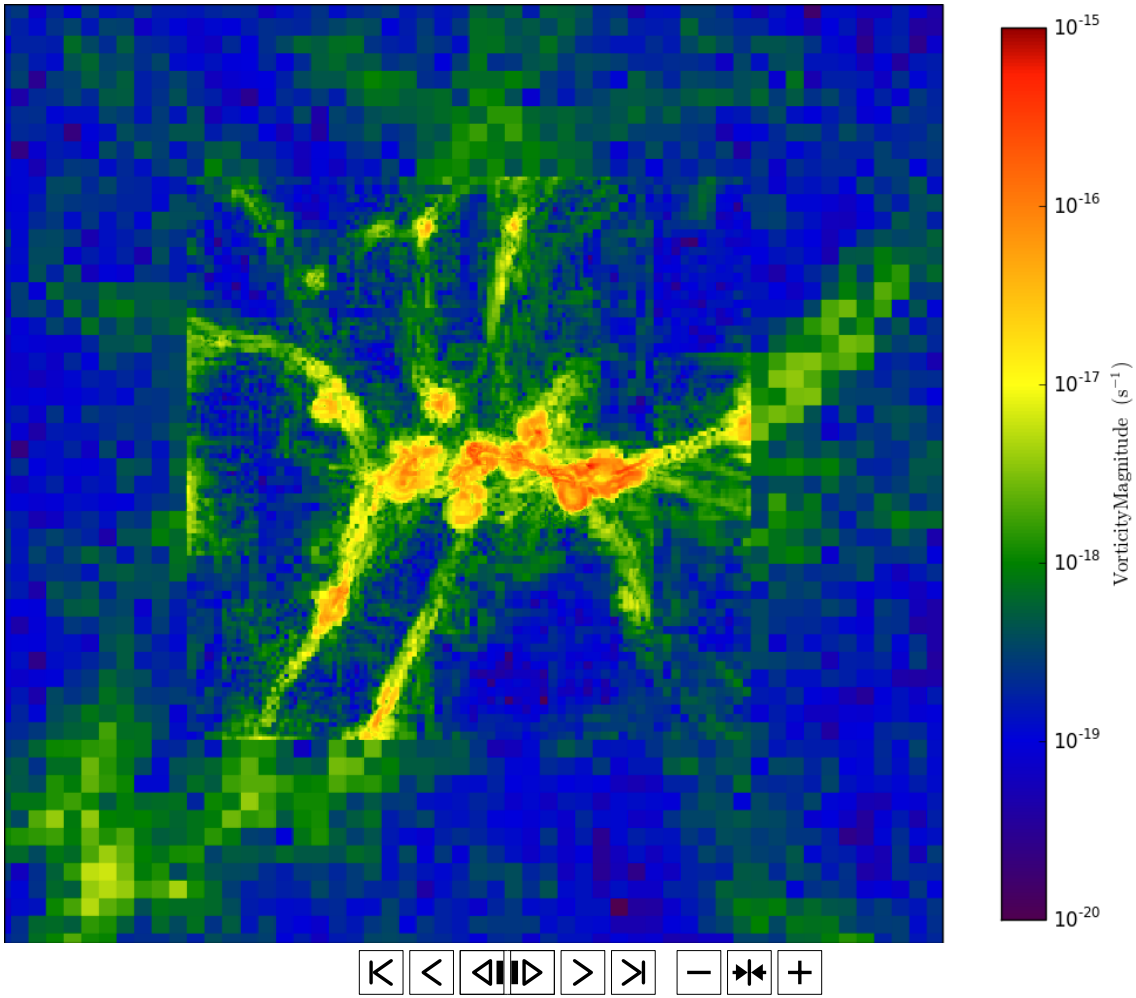
Groups are not the clusters



Panel1: Temperature Vs Mass of the group/cluster. **Panel2:** X-ray Vs Mass.

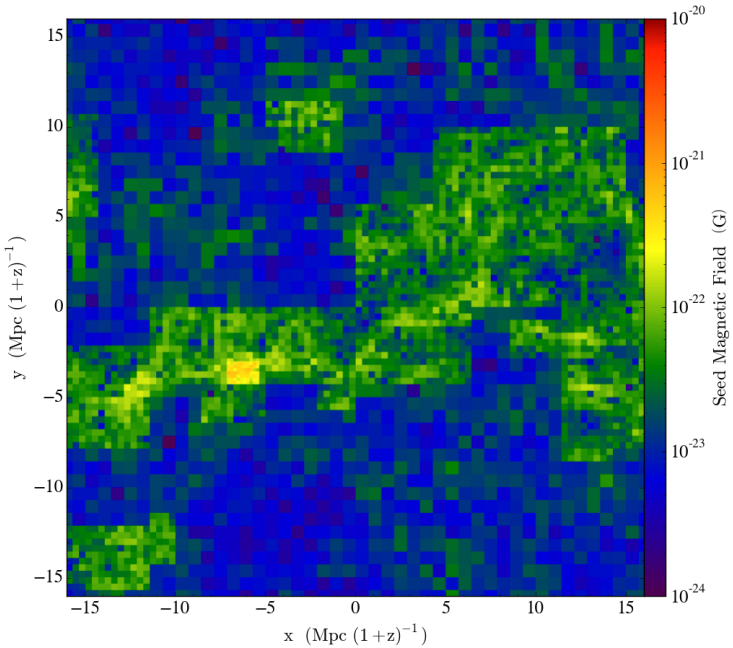
But, these are usually not the independent observables...

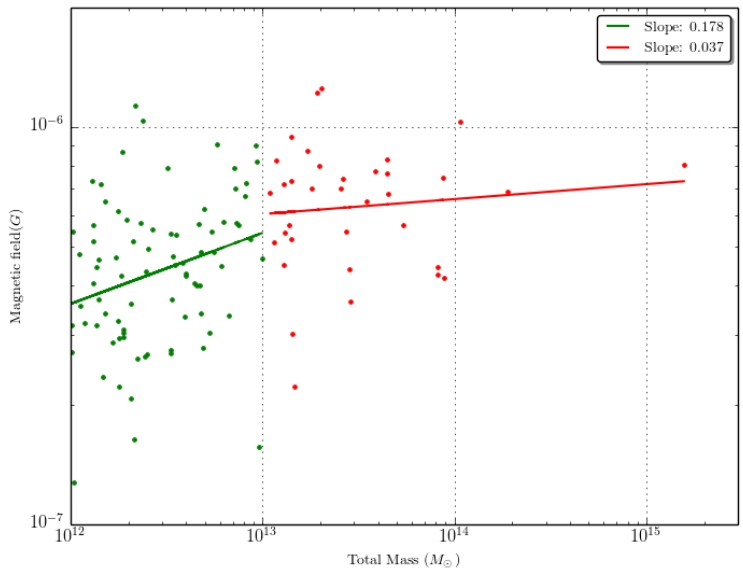
Turbulence in the large scale structures



Vorticity $\mathbf{w} = \nabla x \mathbf{v}$

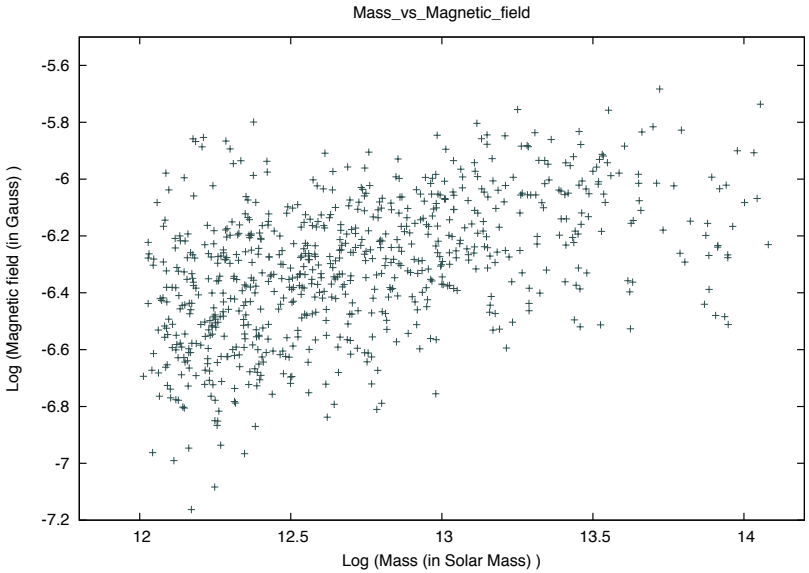
Cosmic Magnetism in Groups

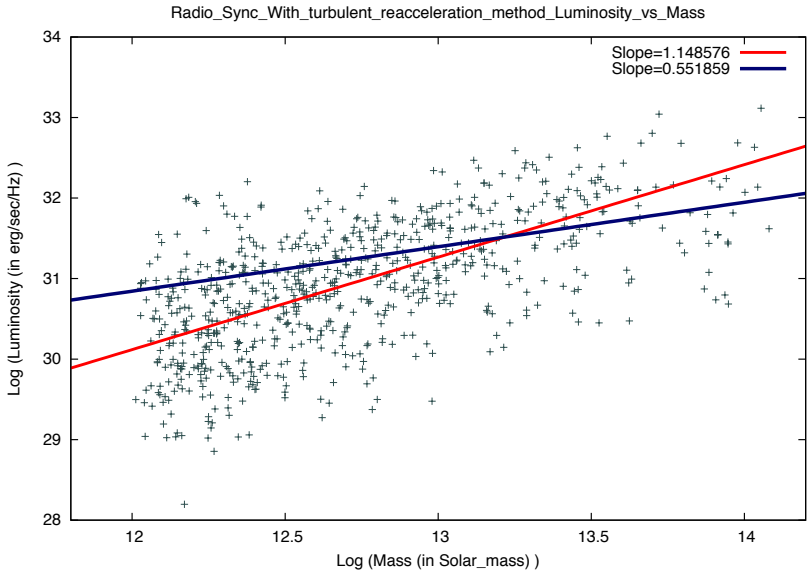




- Groups are seen to be in unstable state with lots of turbulence
- Seed magnetic field in clusters directly related to vorticity/turbulence in the medium
- Results show, at the epoch of re-ionisation itself, groups have reached the seed magnetic field of 10^{-21} Gauss almost same as that of clusters
- With an order less in mass, groups amplifies Cosmic Magnetic field to almost at the cluster level i.e. μ Gauss [$B_{sat} \propto \sqrt{4\pi\rho v_{rms}^2}$ (Subramanian et al. 1998)]

Radio emission from the possible haloes



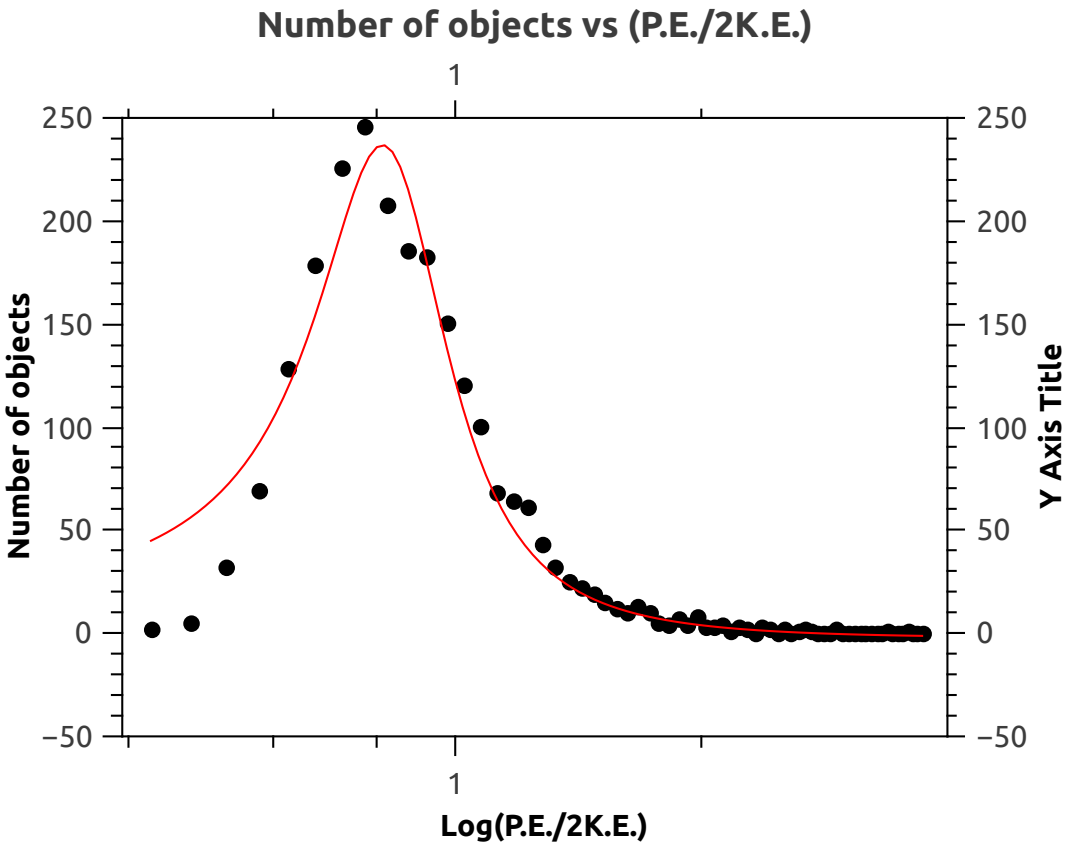


Panel 1: Magnetic field strength Vs Mass **Panel 2:** Radio Luminosity Vs Mass

Observational data from SDSS group catalogue

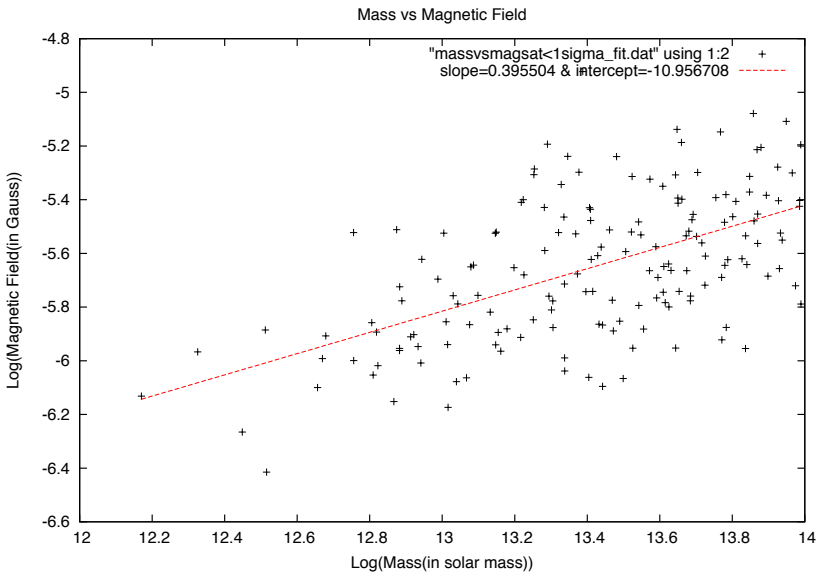
- The Sloan Digital Sky Survey or SDSS is the biggest and most sensitive sky survey in Optical wavelength
- In Data Release 10 (SDSS-DR10) of SDSS, information for a total of 18,48,851 galaxies are available within a sky patch of 14,555 square degrees
- A Galaxy Group catalogue is prepared by Tempel et al. 2014, an they listed 82,458 galaxy groups by defining groups as an object having atleast 2 galaxies and choosing suitable linking length in FoF method
- We have put further cut off to ensure a pure group property. We took groups with atleast 10 candidates and mass above 10^{12} $M_{\odot}$. This will remove the possibility of dominance of some individual galaxies in the determination of group properties. With this constraints, we prepared the final list of $\sim$ 2500 groups for our study

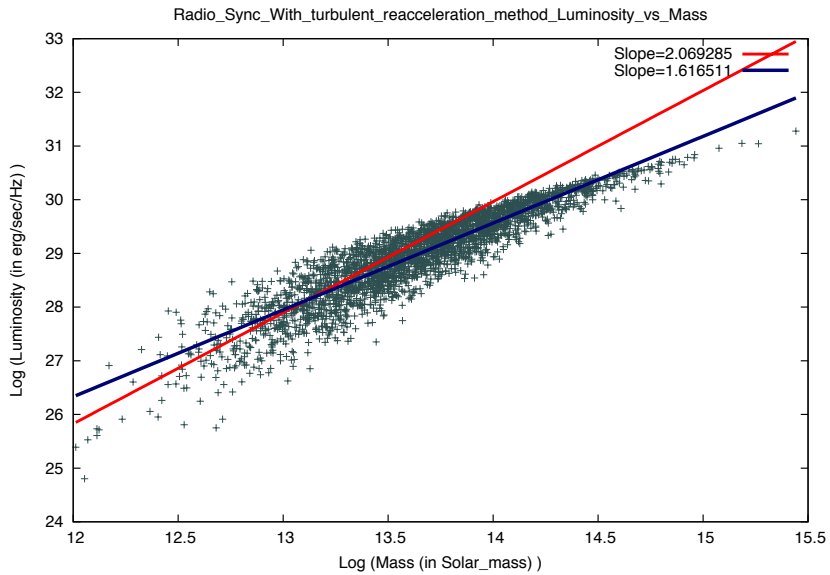
Virialization relation: Potential energy = 2 x Kinetic Energy



Groups and clusters from SDSS data

Magnetic field strength and radio emission





Panel 1: Magnetic field strength Vs Mass **Panel 2:** Radio Luminosity Vs Mass

Radio flux

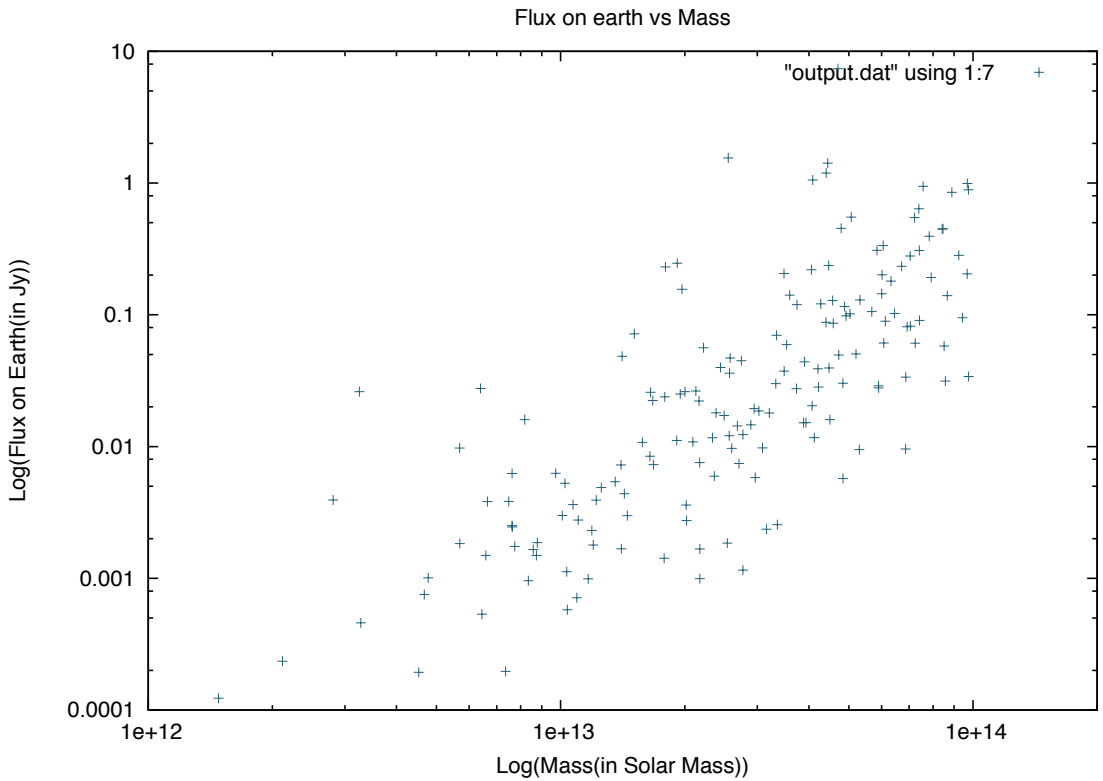
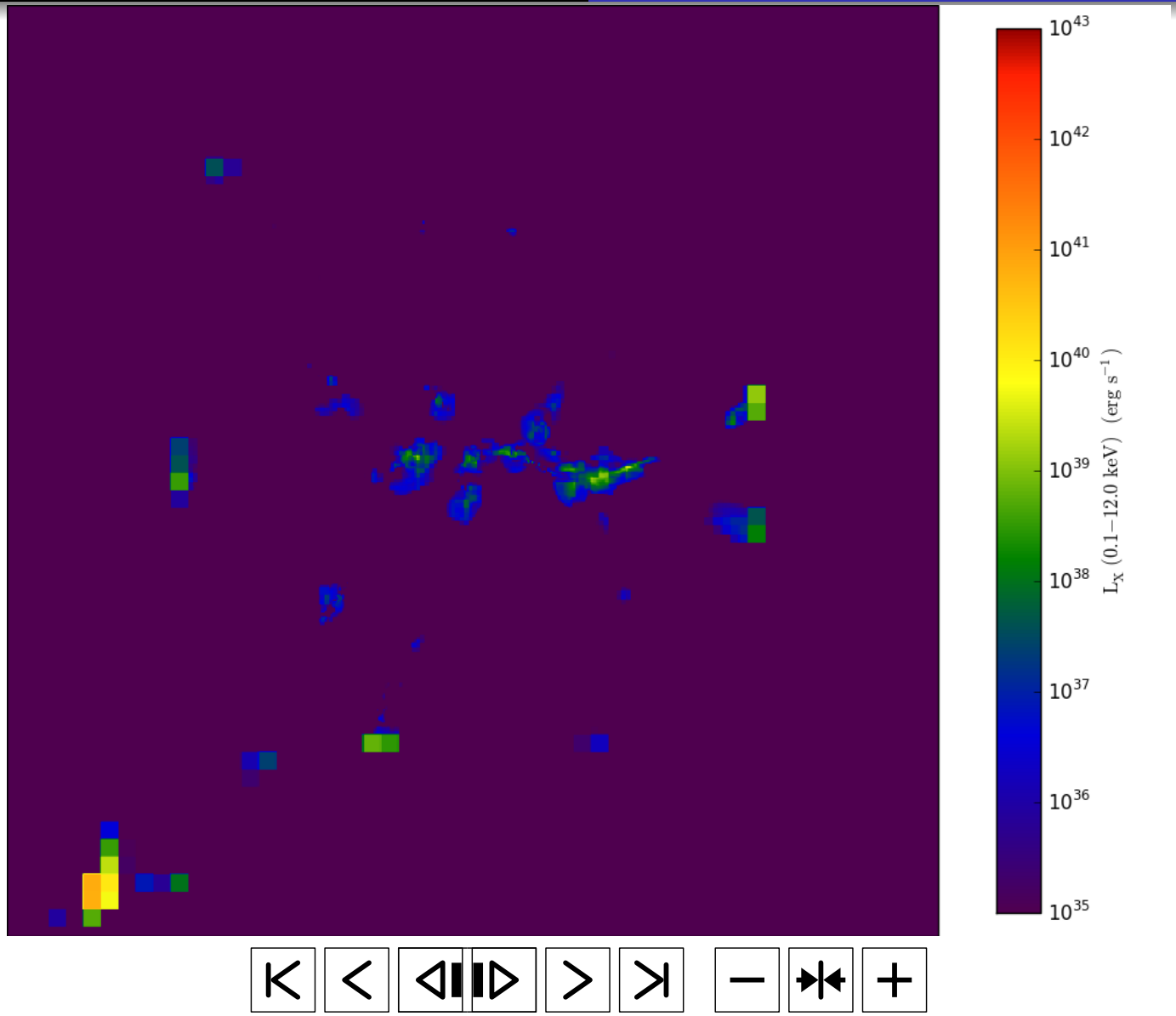


Figure : SDSS Groups

- Galaxy groups are not the scaled down version of Galaxy clusters
- Unlike Galaxy Clusters, groups are far from virialization and are in a highly turbulent phase
- They show different scaling law for Radio emission and mass.
- Cosmic magnetic field is amplified in the galaxy groups almost at the same level that of clusters
- Being at high dynamically active state, groups possibly soon be observed in plenty with the new generation telescopes highly sensitive telescopes

Thank You !


10^{43}
10^{42}
10^{41}
10^{40}
10^{39}
10^{38}
10^{37}
10^{36}
10^{35}
$L_X\ (0.1-12.0\ \mathrm{keV})\ (\mathrm{erg\ s^{-1}})$

Cosmology parameters

- Flat ΛCDM cosmology with $\Omega_m = 0.2743$, $\Omega_b = 0.0458$, $\Omega_\Lambda = 0.7257$, h = 0.702 (E. Komatsu et al., 2009)
- Primordial spectrum normalization $\sigma_8 = 0.816$
- Ideal equation of state for the gas is used with $\gamma = \frac{5}{3}$

Simulation parameters

- Simulation box size: 128^3 Mpc h^{-1}; root grid 64^3
- 2 static grids and 6 levels of Adaptive Mesh Refinement (AMR)
- Effective resolution: 31.25 kpc h^{-1}
- Shock waves as AMR criteria
- Starting redshift is z=60, end redshift z=0