SKA AND THE COSMOLOGICAL EVOLUTION OF CLUSTER MAGNETIC FIELDS

MARTIN KRAUSE

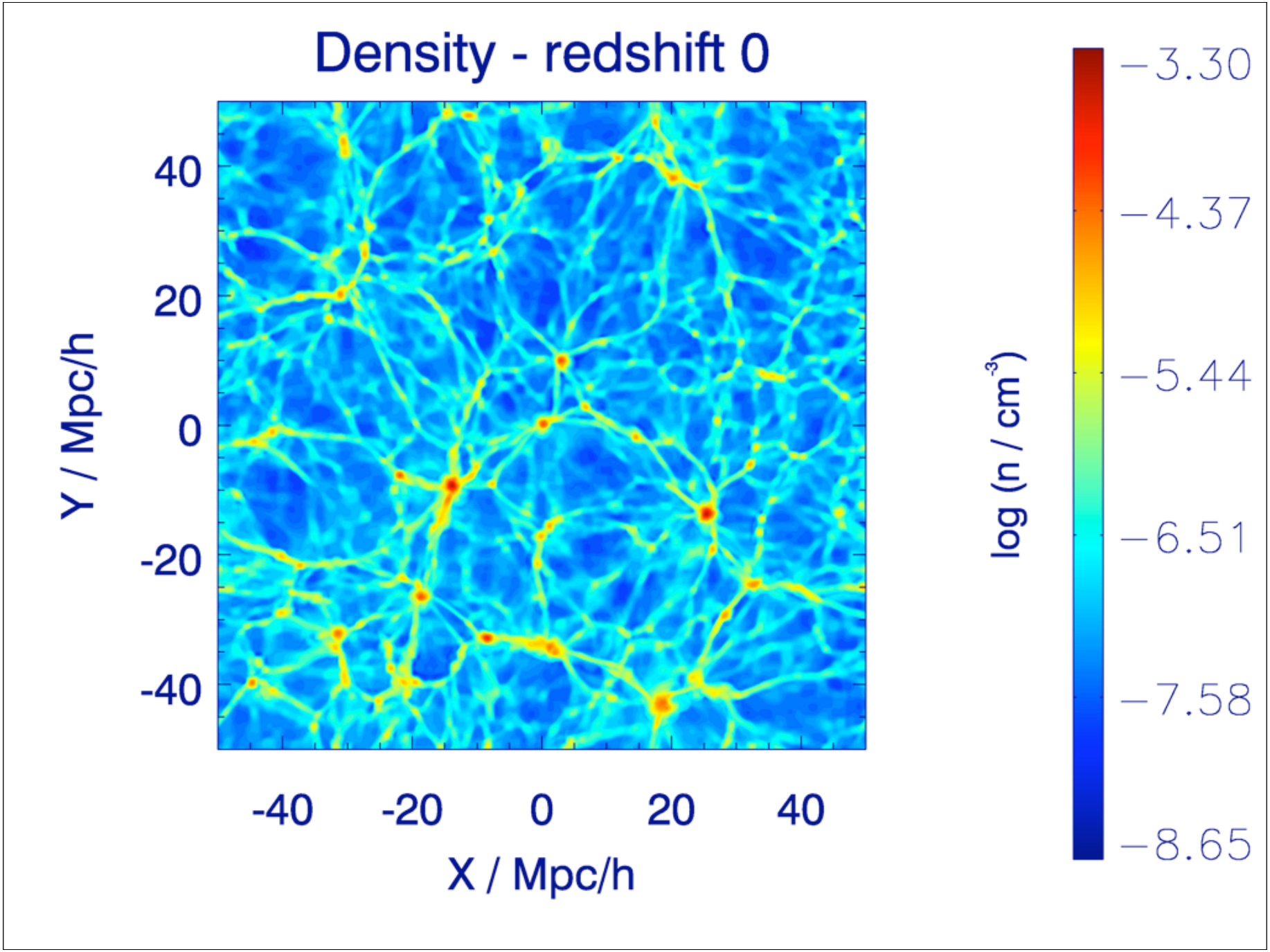
UNIVERSITY OF CAMBRIDGE,

UNIVERSITÄTSSTERNWARTE MÜNCHEN &

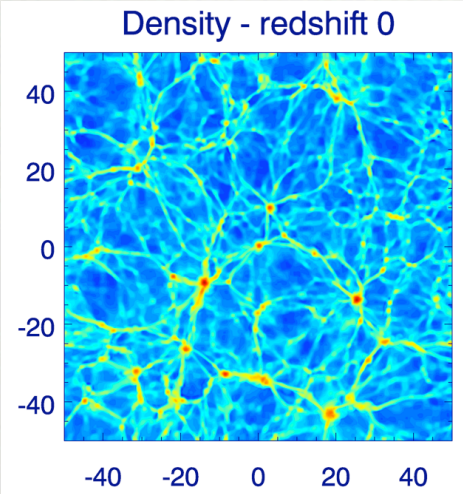
MAX-PLANCK-INSTITUT FÜR EXTRATERRESTRISCHE PHYSIK

COLLABORATORS:

PAUL ALEXANDER, ROSIE BOLTON, DONGSU RYU, JOERN GEISBUSCH

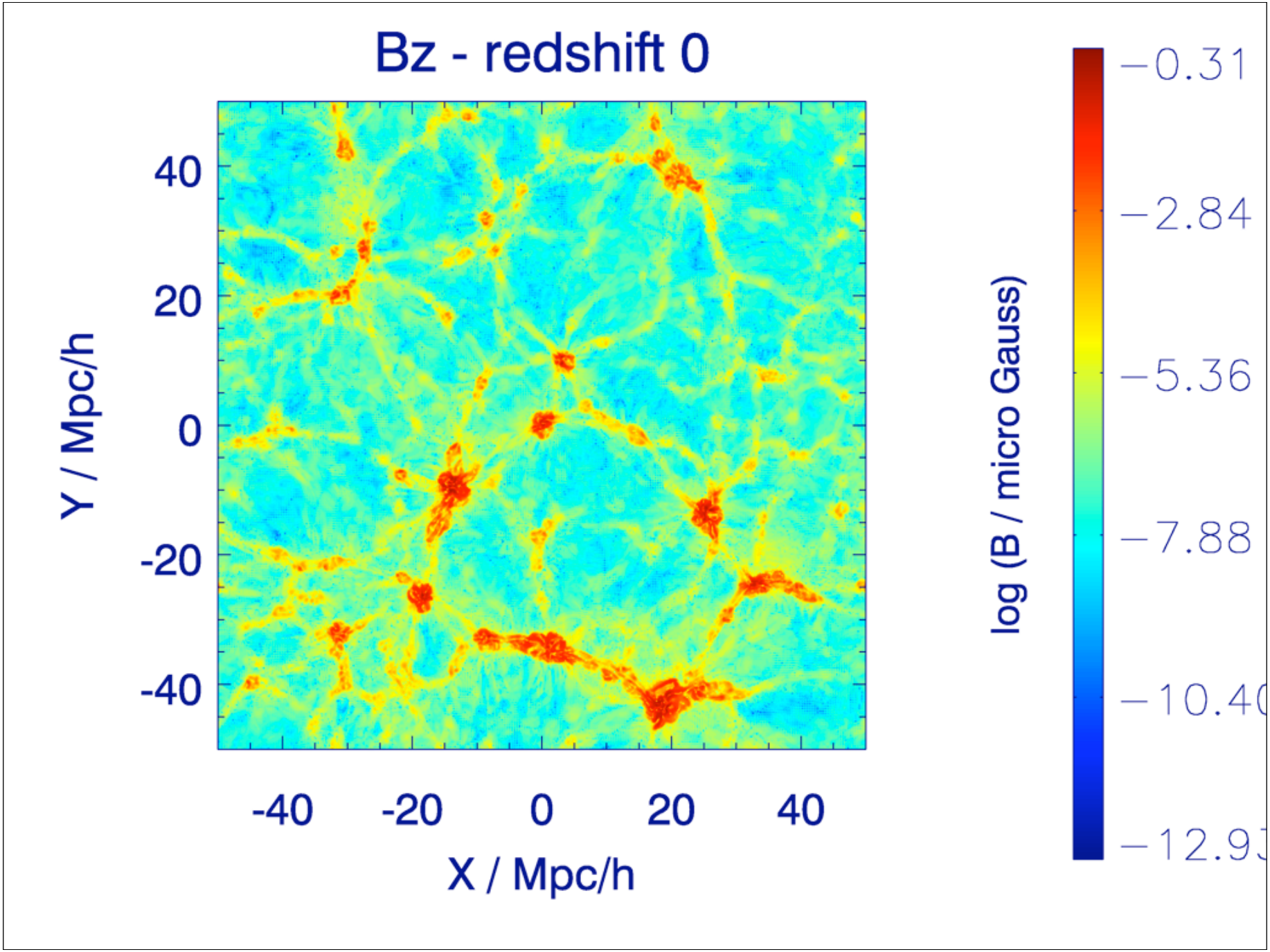

Density - redshift 0
40
20
0
-20
-40
Y / Mpc/h
-40
-20
0
20
40
X / Mpc/h
log (n / cm^{-3})
−3.30
−4.37
−5.44
−6.51
−7.58
−8.65

ELECTRON DENSITY

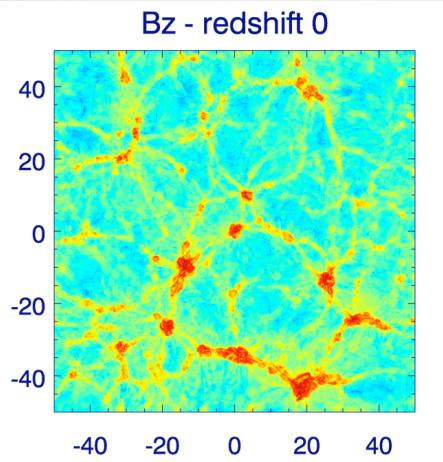


COSMOLOGICAL SIMULATION, CREDITS: DONGSU RYU

- DENSITY OF ELECTRONS WELL KNOWN:
  - COSMOLOGICAL PARAMETERS, E.G. BARYON FRACTION
  - COSMOLOGICAL EVOLUTION / SIMULATIONS
  - OBSERVATIONS, E.G. X-RAY MEASUREMENTS


Bz - redshift 0
40
20
0
-20
-40
Y / Mpc/h
-40
-20
0
20
40
X / Mpc/h
log (B / micro Gauss)
−0.31
−2.84
−5.36
−7.88
−10.40
−12.93

MAGNETIC FIELD



COSMOLOGICAL SIMULATION, CREDITS: DONGSU RYU

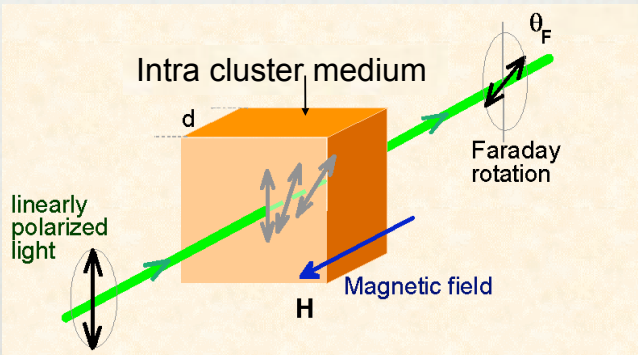
- MAGNETIC FIELDS POORLY KNOWN
  - OBSERVATIONS (SYNCHROTRON, INVERSE COMPTON, FARADAY ROTATION): FEW MICROGAUSS
  - IN VOIDS: VERY SMALL FIELDS, PRODUCED IN EARLY UNIVERSE, UNKNOWN
  - IN CLUSTERS: ENHANCED BY TURBULENT DYNAMO TO EQUIPARTITION, PROBLEM: TURBULENT ENERGY UNKNOWN

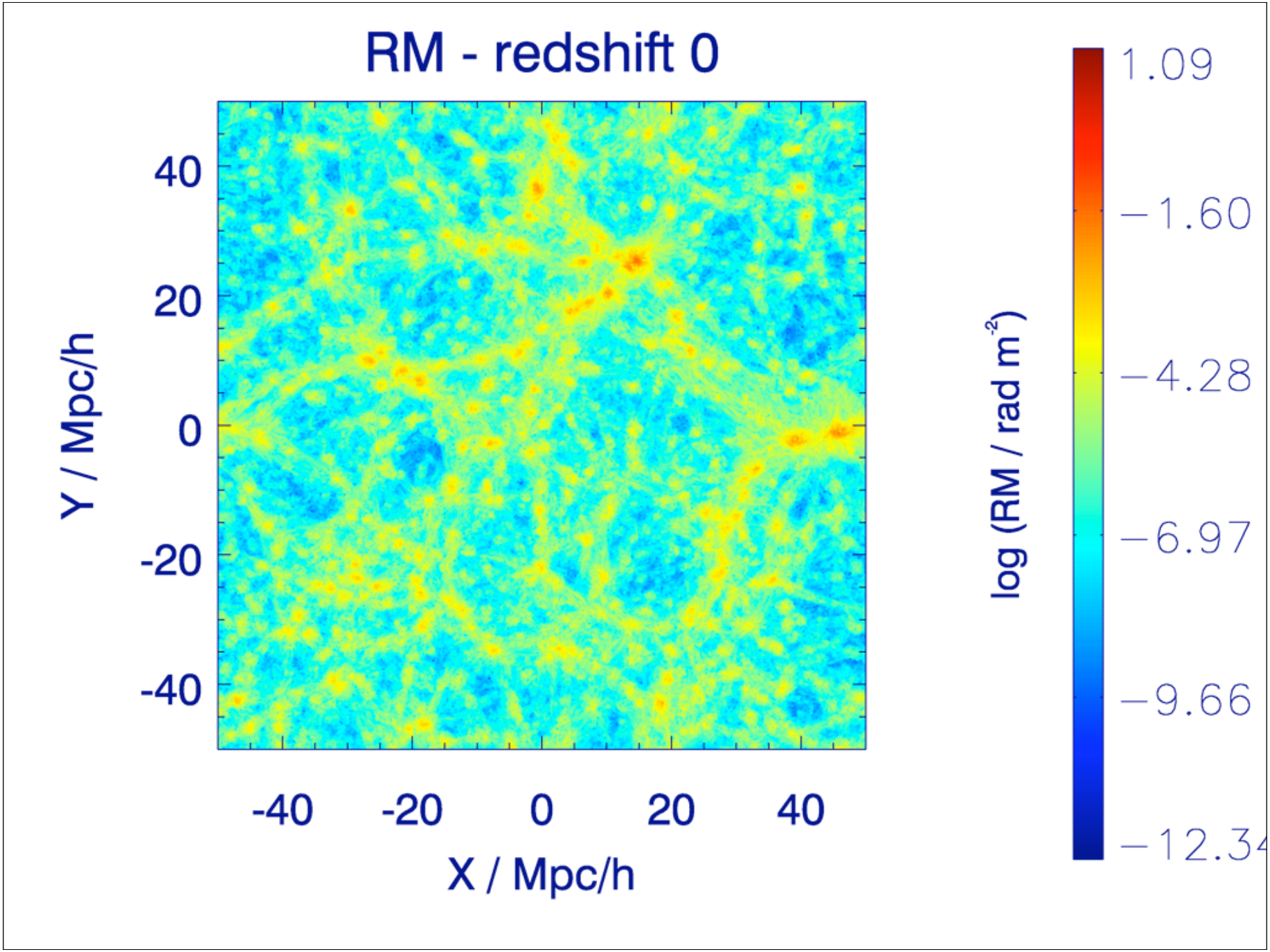
REVISION – FARADAY ROTATION

- MEASURE MAGNETIC FIELDS THROUGH FARADAY ROTATION OF PLANE OF POLARISATION OF LIGHT FROM BACKGROUND SOURCE. ROTATION DEPENDENT ON WAVELENGTH – MEASURE ROTATION IN SEVERAL CHANNELS.
- ONLY GIVES LINE INTEGRAL – B PARALLEL TO LOS.
- REQUIRES ELECTRON DENSITY TO BE KNOWN (X-RAY).

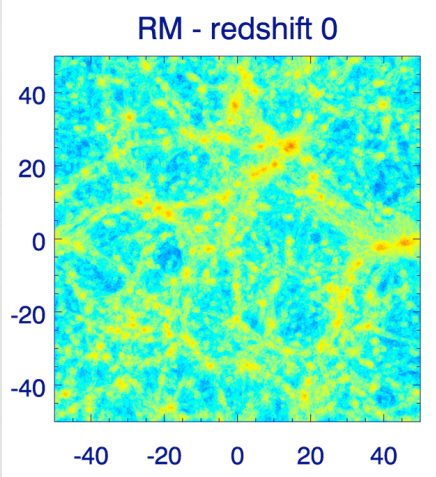
$$RM = 812 \int n_e B_{LOS} dl$$ Radians m^{-2}

$$\Delta\vartheta = RM \times \lambda^2 / (1+z)^2$$




RM - redshift 0
Y / Mpc/h
40
20
0
-20
-40
-40
-20
0
20
40
X / Mpc/h
log (RM / rad m^{-2})
1.09
−1.60
−4.28
−6.97
−9.66
−12.34

FARADAY ROTATION: MEASUREMENT



COSMOLOGICAL SIMULATION, CREDITS: DONGSU RYU

- ☐ MEASURE RM AND N_E
- ☐ INFER B
- ☐ CAVEAT: FIELD STRUCTURE/ REVERSALS - LATER

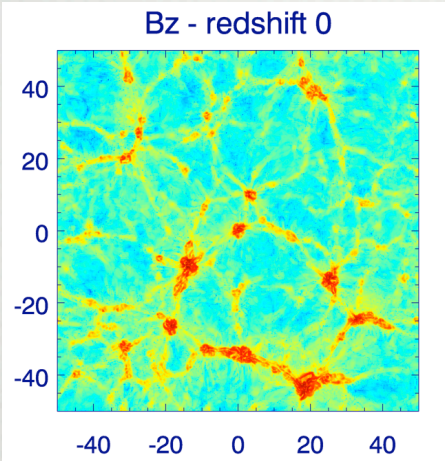
OVERVIEW

- MAGNETIC FIELDS: ORIGIN AND AMPLIFICATION
- CURRENT FARADAY ROTATION STUDIES
- THE FUTURE: TOWARDS THE SKA, SOURCE STATISTICS
- SYNERGIES: ELECTRON DENSITIES AT HIGH REDSHIFT

MAGNETIC FIELDS: ORIGIN AND AMPLIFICATION

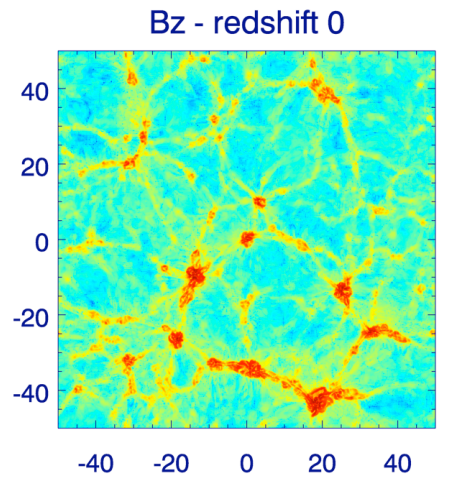
- SEED FIELDS:
  - BIERMANN BATTERY: $M_E \neq M_P \Rightarrow \underline{E}_{BIER} = -\nabla P / E\, N_E$, CURL $\Rightarrow$ INDUCTION SOURCE $\Rightarrow$ B OF ORDER 10^{-20} GAUSS
  - THOMSON CROSS SECTION $\propto 1/M \Rightarrow$ PHOTON/ E-P SCATTERING ASSYMETRY/ RECOMBINATION ERA $\Rightarrow 10^{-30} - 10^{-21}$ GAUSS
  - SEEDED IN STARS (SIM.: AGN) AND EJECTION $\Rightarrow < 10^{-9}$ GAUSS
  - VACUUM FLUCTUATIONS / INFLATION $\Rightarrow$ UP TO 10^{-9} GAUSS, NOW

MAGNETIC FIELDS: ORIGIN AND AMPLIFICATION



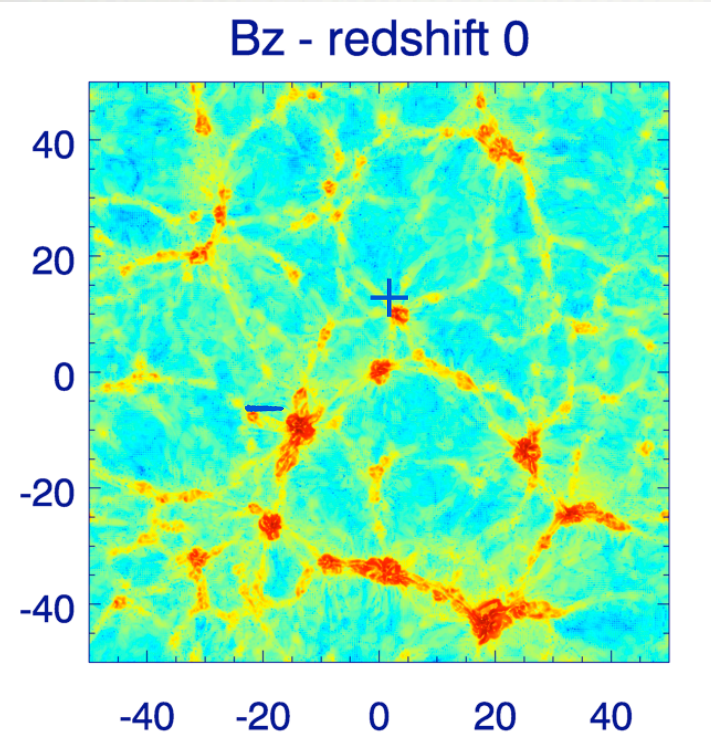
- AMPLIFICATION
  - HELICAL/ MEAN FIELD DYNAMOS: GALAXIES
  - RELEVANT IN CLUSTERS: TURBULENT DYNAMO - FIELD LINE STRETCHING ⇒ $B \propto L$ ⇒ L GROWS (RANDOM WALK) ⇒ EXPONETIAL GROWTH ON EDDY TURNOVER TIMESCALE, SATURATION AT EQUIPARTITION

MAGNETIC FIELDS: ORIGIN AND AMPLIFICATION



- CONCLUSION:
  - MAGNETIC FIELDS NEED A SPECIFIC SEED MECHANISM, DYNAMOES FOR AMPLIFICATION AND SUSTAINING
  - MF MEASUREMENTS PROMISE UNDERSTANDING OF:
    - SEED MECHANISM
    - AMPLIFICATION/ CLUSTER DYNAMICS
    - PLASMA PHYSICS / TRANSPORT COEFFICIENTS

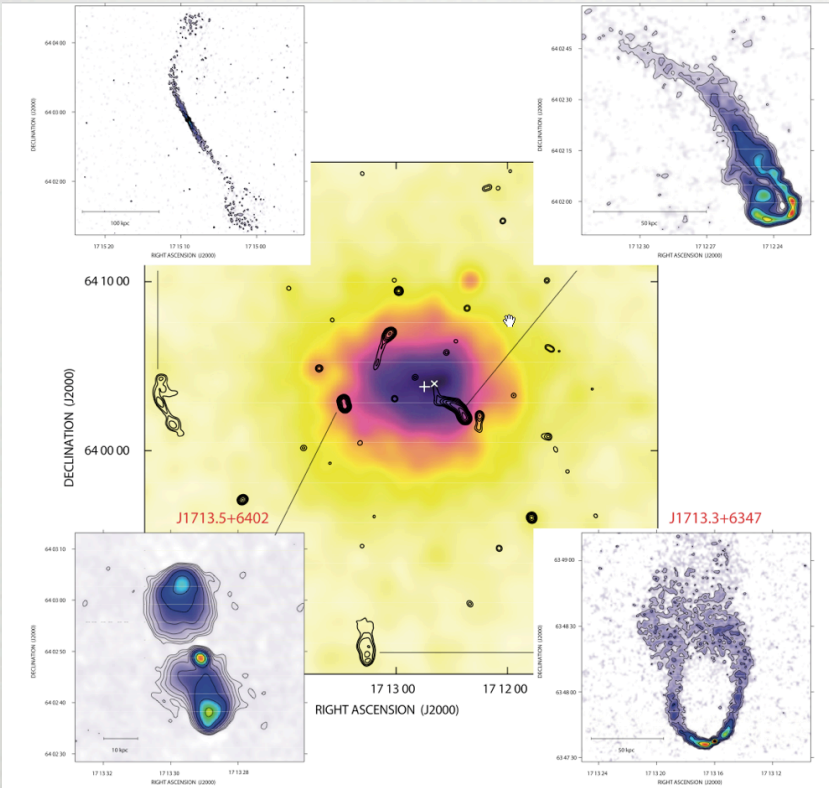
MAGNETIC FIELDS: ORIGIN AND AMPLIFICATION



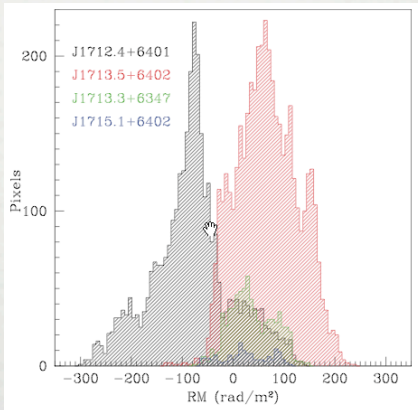
- HOW MAY WE MEASURE THIS?
- DIV(B) = 0
  - AMPL. EARLY UNIVERSE FIELDS, COHERENT MPC SALES: $\langle RM \rangle \neq 0$
  - LOCALLY DYNAMO AMPLIFIED FIELDS, COHERENT ON CLUSTER SCALES: $\langle RM^2 \rangle \neq 0$

CURRENT FARADAY ROTATION STUDIES

A2255 - GOVONI ET AL.



- FEW SOURCES/CLUSTER
- $\langle RM \rangle = 0$
- $\langle RM^2 \rangle = 100$ RAD/M^2
- KOLMOGOROV TURBULENCE ?



THE FUTURE: TOWARDS THE SKA

- HOW MAY WE IMPROVE?
  - NEED MORE INDEPENDENT SIGHTLINES
    >> MORE SOURCES: $\Delta\langle RM\rangle \propto 1/\sqrt{N}$,

    CURRENTLY: $\Delta\langle RM\rangle \sim 10\,RAD/M^2$
  - ALSO FOREGROUND SURCES (GALACTIC CONTR.)
- HOW MUCH WILL WE IMPROVE? SIMULATIONS!

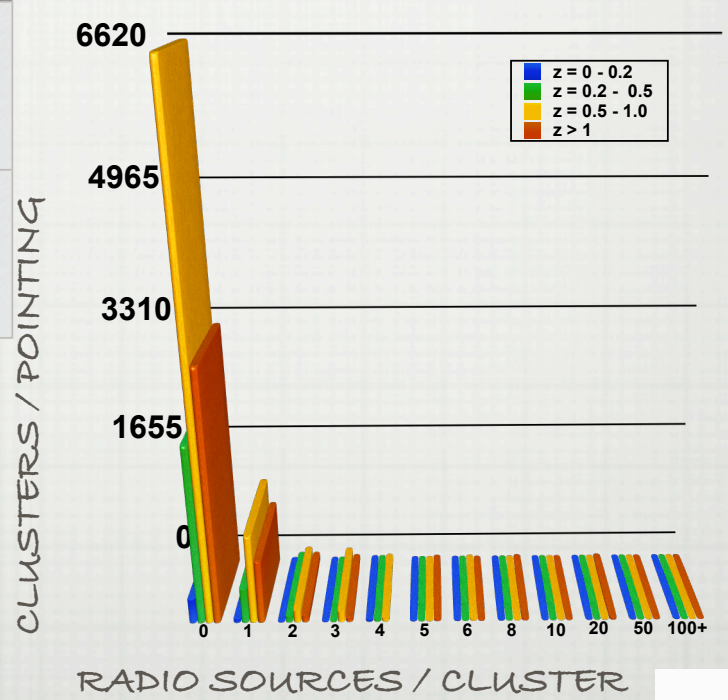
1. CLUSTERS AND RADIO SOURCES FROM COSMOLOGICAL CALCULATION (POPULATION OF DENSITY FIELD EVOLVED ACCORDING TO LINEAR THEORY)

EXPECTED RM'S STATISTICS

	VLA	SKA phase1	SKA full
sens.:1h/ 10^{-6} Jy	17	7	0.1
field of view / deg	$.6/f^2$	200	200

- STILL FEW BG SOURCES
- FIRST HIGH Z MEASUREMENTS

Phase I SKA, 1h pointing

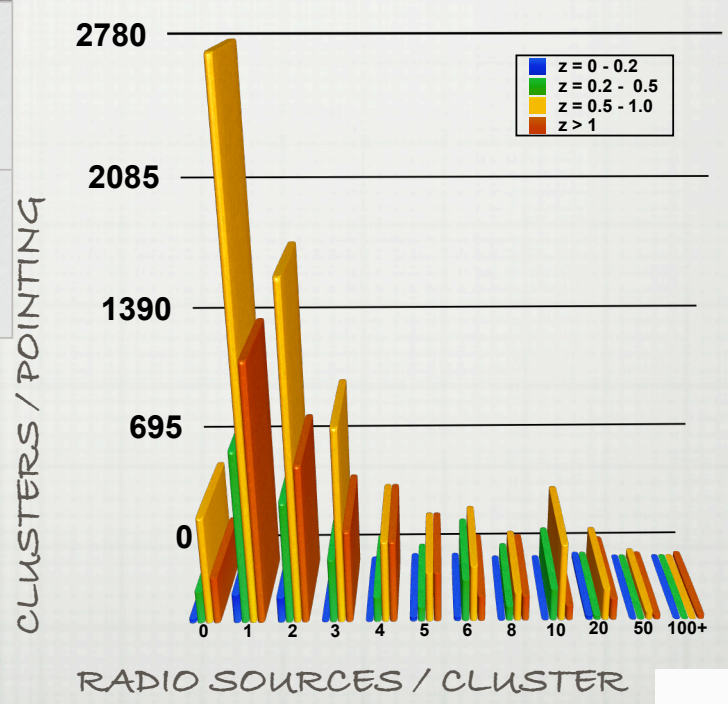


EXPECTED RM'S STATISTICS

	VLA	SKA phase1	SKA full
sens.:1h/ 10^{-6} Jy	17	7	0.1
field of view / deg	$.6/f^2$	200	200

- BETTER THAN PRESENT DAY STATISTICS AT Z>1
- GOOD STATISTICS, 1000S OF CLUSTERS WILL HAVE MEASURED RMS

Phase1 SKA, 100h pointing

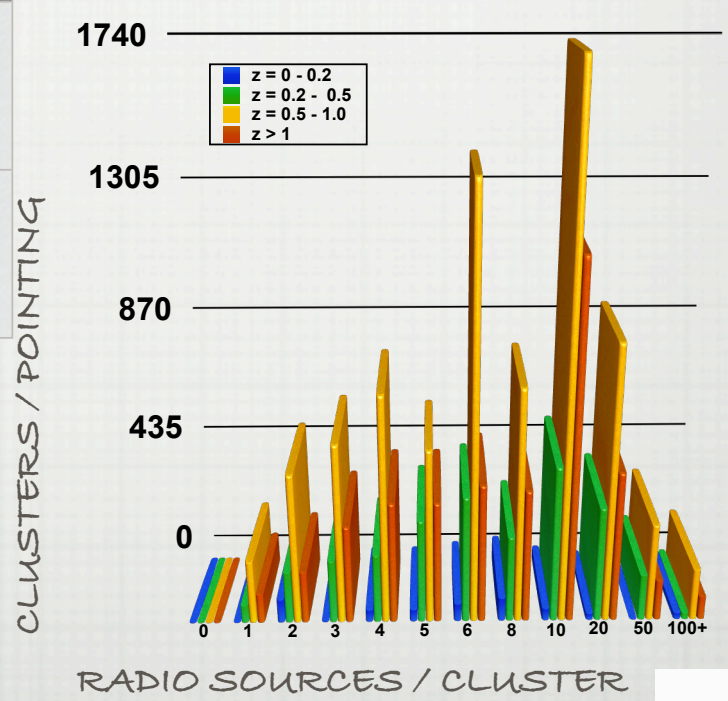


EXPECTED RM'S STATISTICS

	VLA	SKA phase1	SKA full
sens.:1h/ 10^{-6} Jy	17	7	0.1
field of view / deg	$.6/f^2$	200	200

- >100 CLUSTERS WITH 100S OF BG SOURCES EVEN SOME AT Z>1

Full SKA, 1h pointing

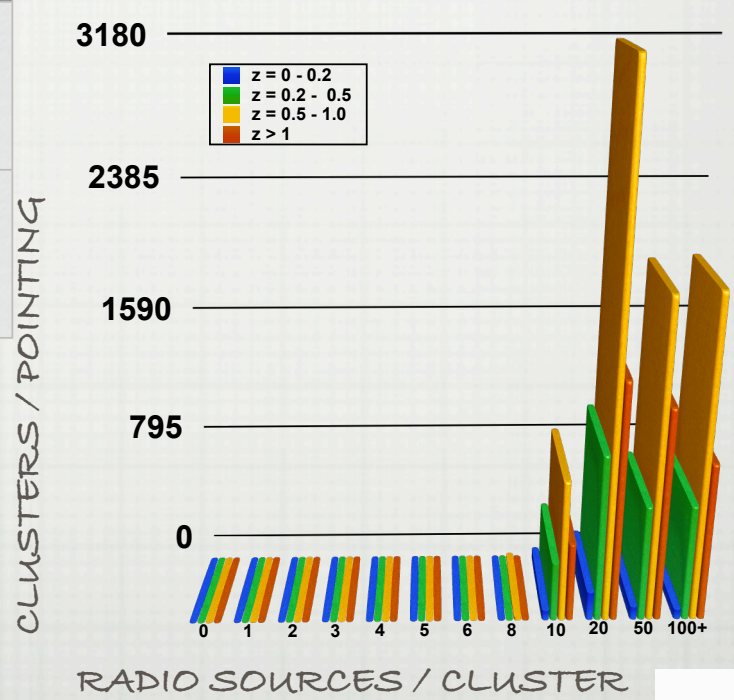


EXPECTED RM'S STATISTICS

	VLA	SKA phase1	SKA full
sens.:1h/ 10^{-6} Jy	17	7	0.1
field of view / deg	$.6/f^2$	200	200

- SOME CLUSTERS WILL HAVE RMS FROM > 10,000 SOURCES
- $\Delta\langle RM\rangle \sim 0.1 RAD/M^2$

Full SKA, 100h pointing



SYNERGIES

- ESP. FOR HIGH REDSHIFT: ELECRON DENSITIES
  - SUNYAEV-ZELDOVICH EFFECT / HIGH FREQUENCY RADIO TELESCOPES
  - THERMAL EMISSION / X-RAY

CONCLUSIONS

- MAGNETIC FIELDS IN CLUSTERS OF GALAXIES MAY HAVE A COMPONENT CORRELATED ON SUPER-CLUSTER SCALE, PRODUCING A SMALL $\langle RM \rangle \neq 0$
- OVERLAID IS A TURBULENCE RELATED CLUSTER SCALE FIELD, PRODUCING $\langle RM^2 \rangle \neq 0$
- TODAY: $\langle RM^2 \rangle \approx 100$ RAD/M^2 $> \langle RM \rangle$, KOLMOGOROV?
- FULL SKA: $>\times 1000$ SOURCES EVEN AT HIGH Z, IMPACTING ON:
  - TURBULENCE / CLUSTER DYNAMICS
  - PLASMA PHYSICS / TRANSPORT COEFFICIENTS
  - LARGE SCALE FIELD DETECTION POSSIBLE