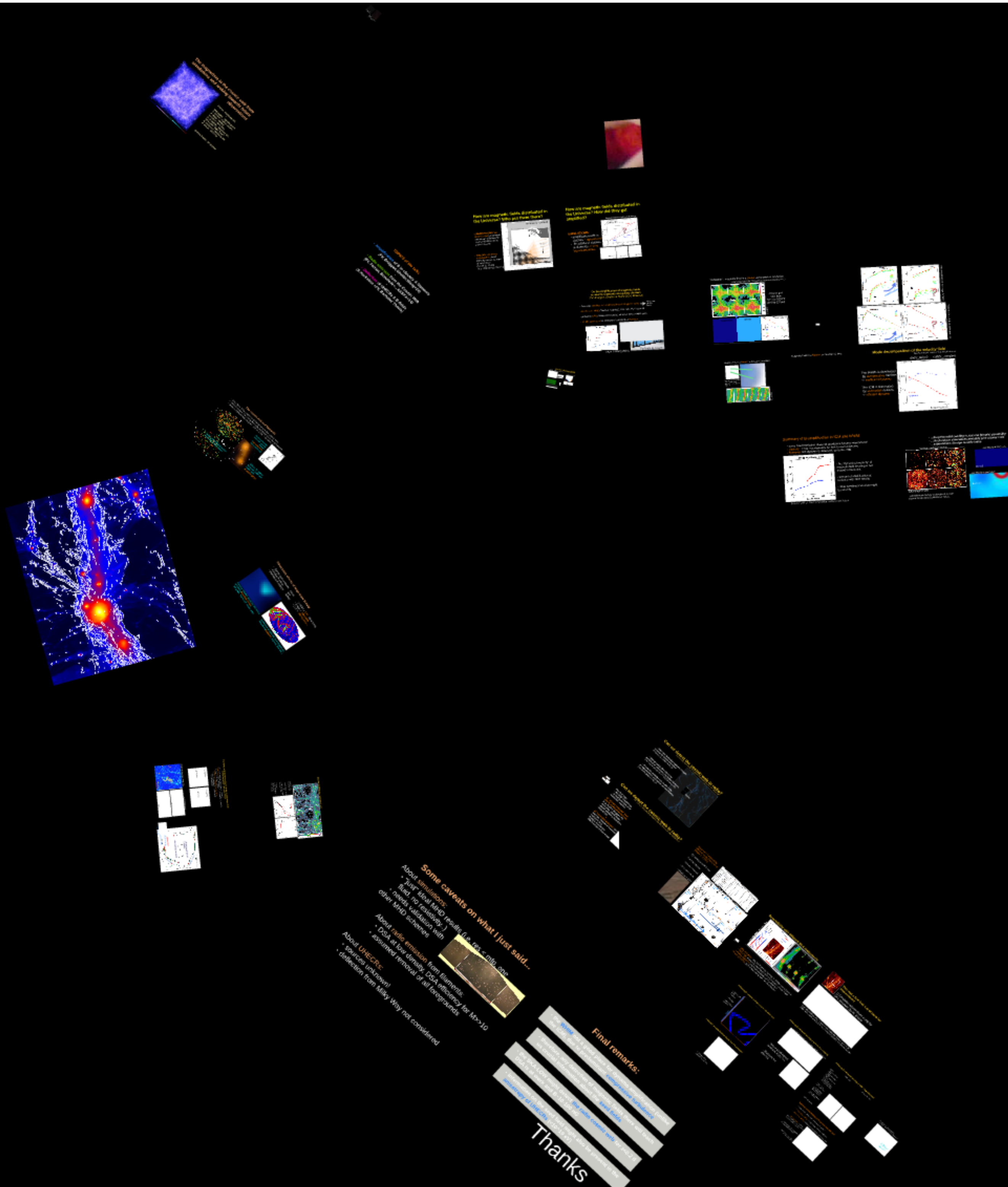
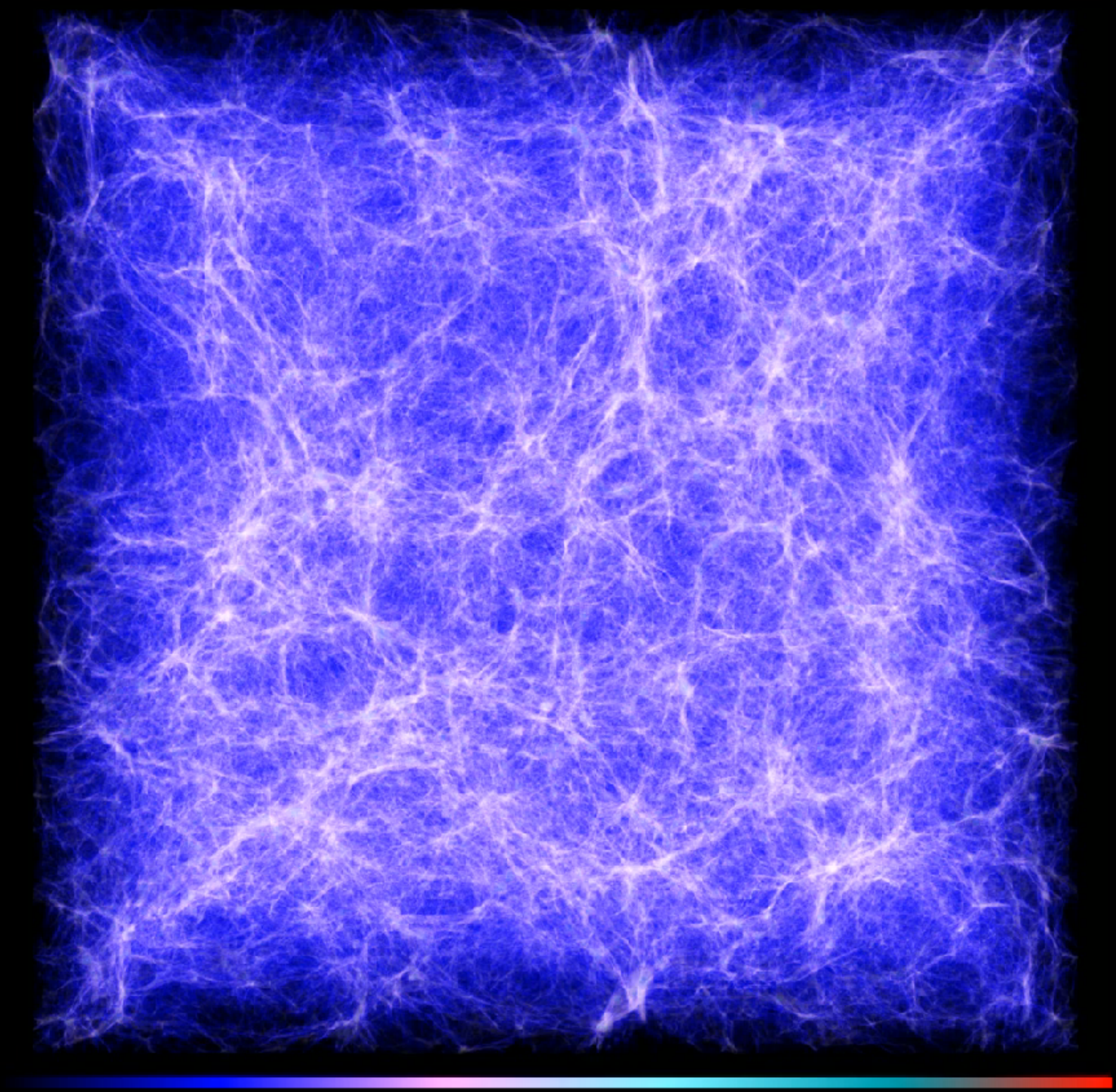

Some caveats on what I just said...
About simulations:
• needs validation with other MHD schemes
About radio emission from filaments:
• DSA at low density, DSA efficiency for M>>10
• assumed removal of all foregrounds
About UHECRs:
• sources unknown
• deflection from Milky Way not considered
Final remarks:
Thanks

The magnetism in the cosmic web from simulations and looking towards future observations



F.Vazza - Hamburg Uni.
+
M.Bruggen - Hamburg Uni.
C. Gheller - CSCS Lugano
P. Wang - NVIDIA
C.Ferrari - Nice Obs.
A. Bonafede - Hamburg Uni.
SKA-LOW "Tiger Team"
S. Hackstein- Hamburg Uni.
R. Braun - SKA Org.

OATS@Trieste - 05.11.2014

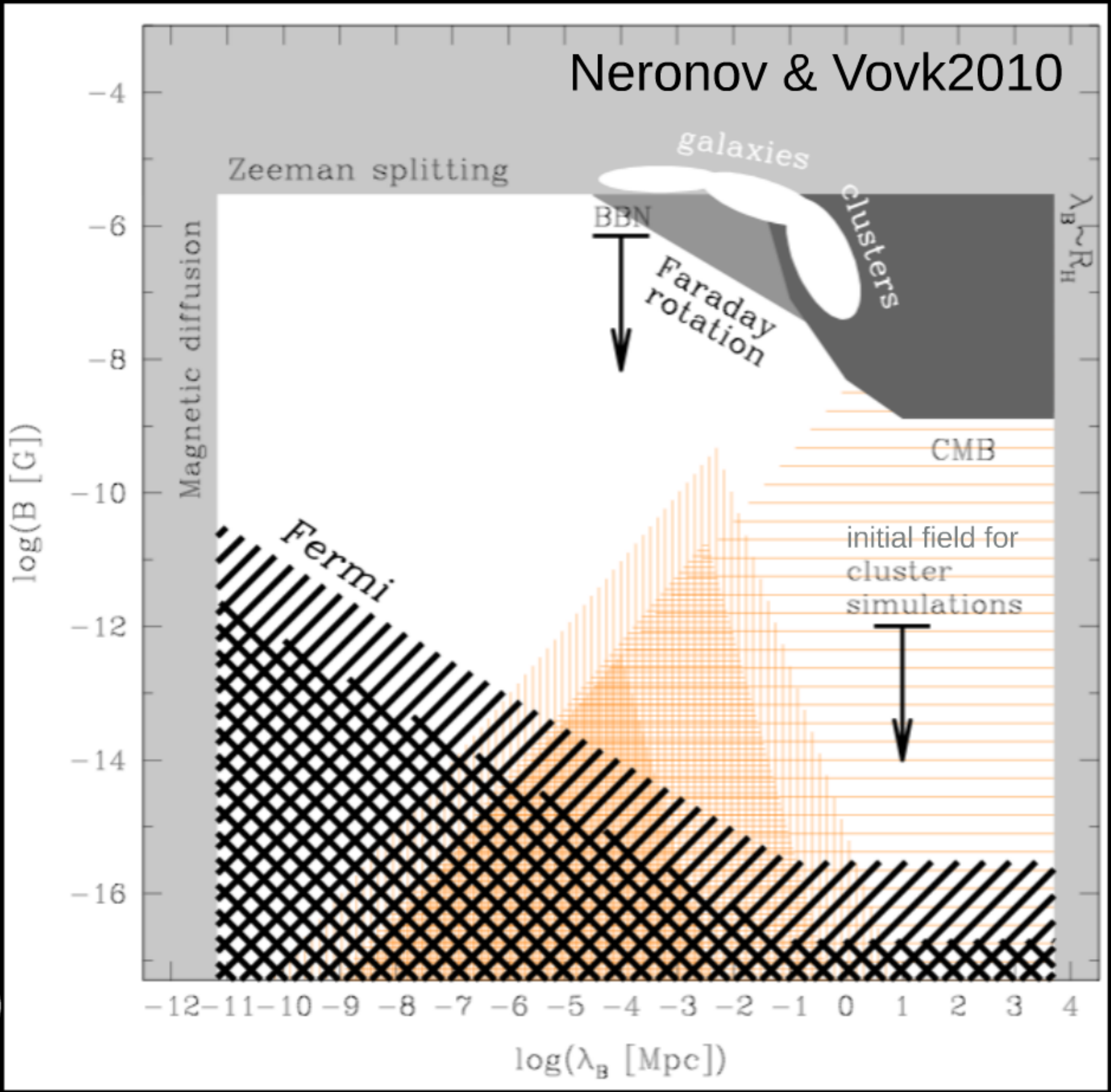
TOPICS of the talks

- ***Amplification** of B in clusters & filaments (FV, Brüggen,Gheller,Wang+14)*
-
- ***Radio emission** from the Cosmic Web (FV, Ferrari, Bonafede+...AASKA+14)*
-
- ***Deflection** of UHECRs & B-fields (S.Hackstein +FV, Bachelor Thesis)*

How are magnetic fields distributed in the Universe? Who put them there?

- **OBSERVATIONS**: big uncertainties on strenght and scales of B-field for most (>99.99%) of the cosmic volume

- **THEORY**: enormous uncertainties about intensity, scales & origin of seed fields (1e-34-1e-10 G!) (e.g. Widrow+11; Ryu+11)

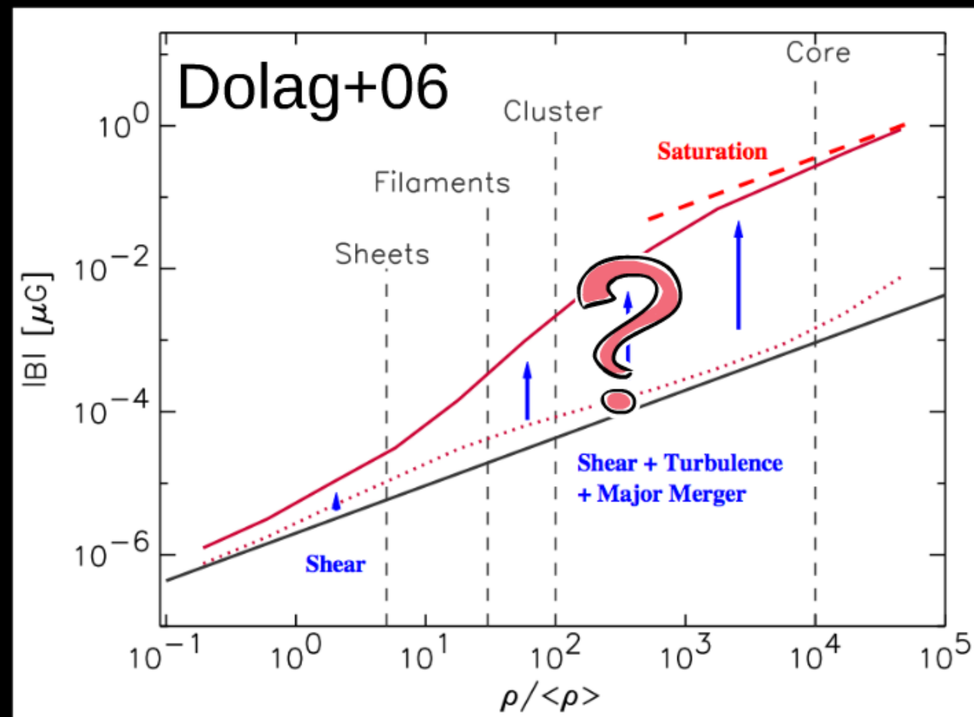


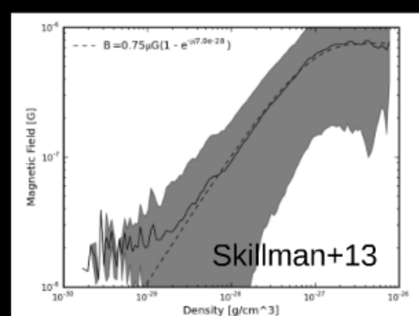
How are magnetic fields distributed in the Universe? How did they get amplified?

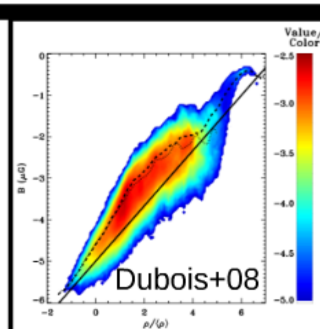
SIMULATIONS:

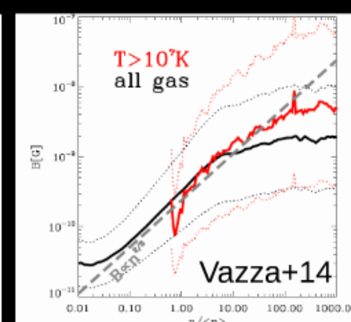
- amplification of B in clusters ~ agreement
- B outside of clusters & filaments -> very big uncertainties

Magnetic field as a function of density





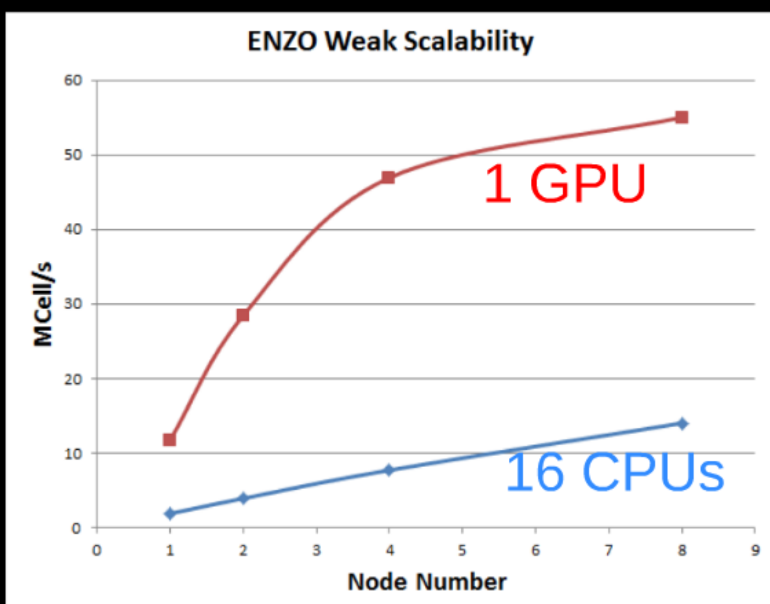




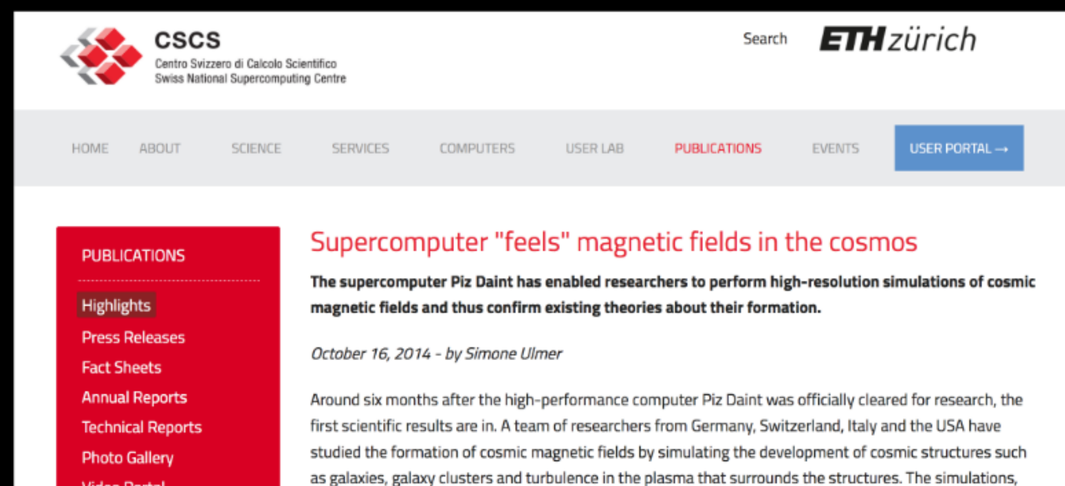
On the amplification of magnetic fields in cosmic filaments and galaxy clusters

(FV, Brüggen, Gheller & Wang 2014, MNRAS)

- Scenario: amplification of primoridal weak magnetic fields → B0=1e-10G, 30>z>0, Pm=1
- ENZO v.3 + MHD ("Dedner cleaning"), HLL solv., PLM reconstr.
- ported on GPU (Wang & Abel 2010): x4 faster (x80 on MHD part)
- 32 Mio core hours for CHRONOS call 2014 on Piz-Daint



(from P.Wang 2010)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Supercomputer "feels" magnetic fields in the cosmos

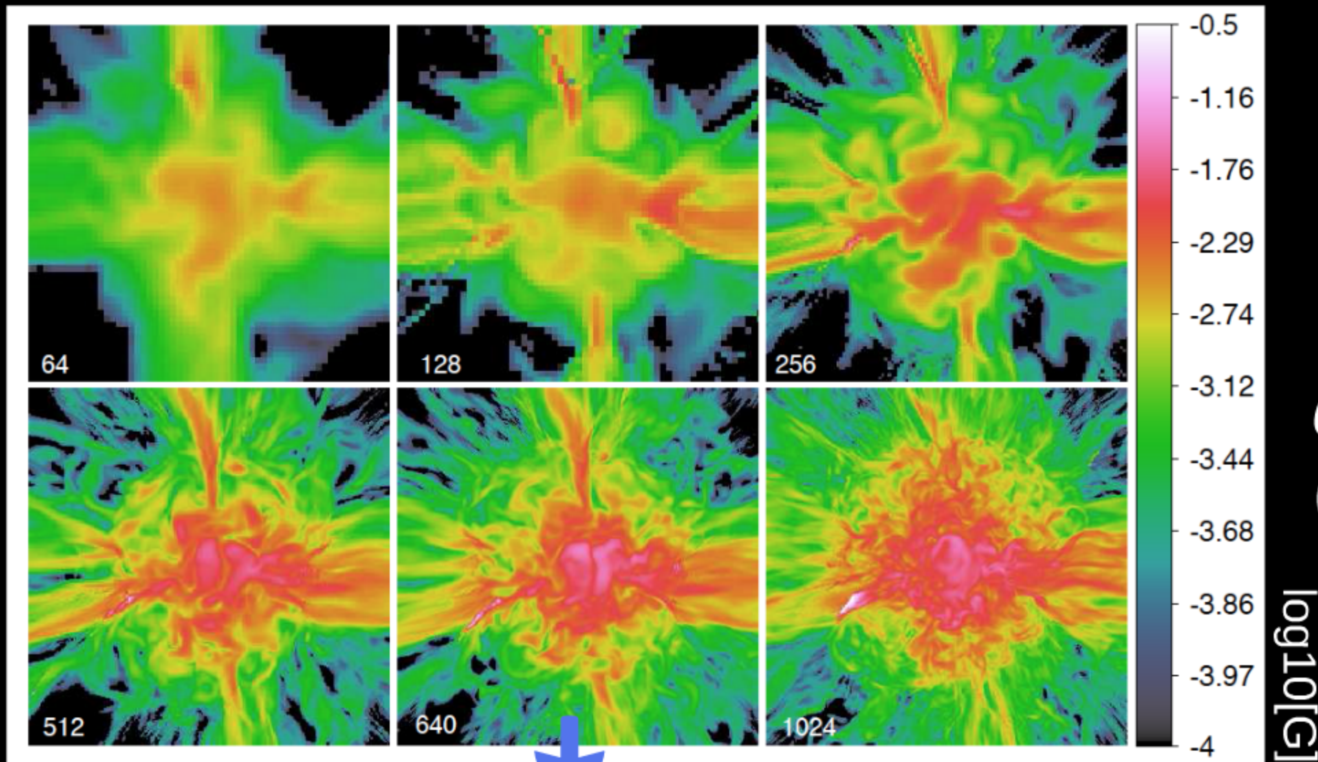
The supercomputer Piz Daint has enabled researchers to perform high-resolution simulations of cosmic magnetic fields and thus confirm existing theories about their formation.

October 16, 2014 - by Simone Ulmer

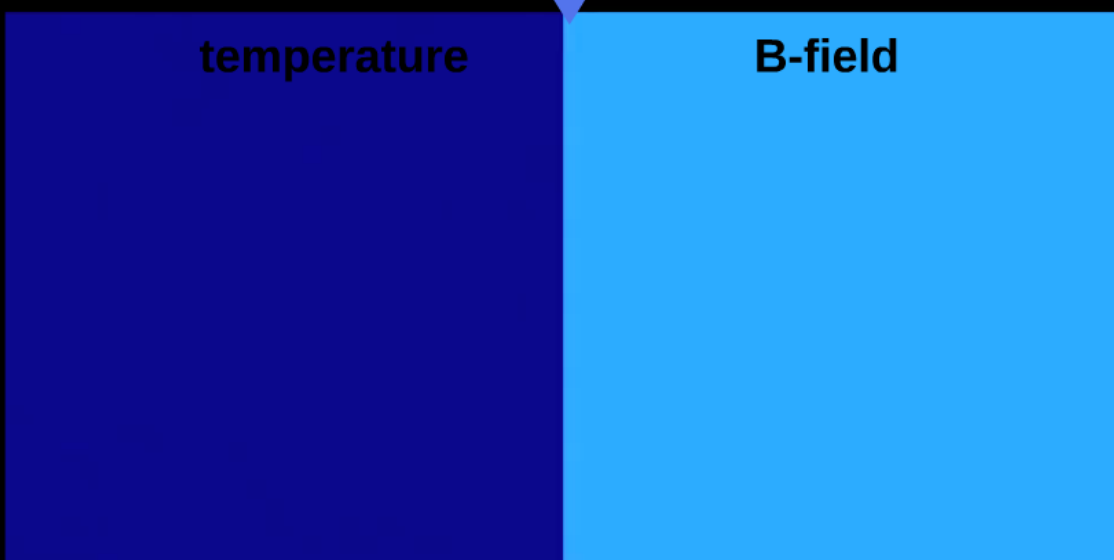
Around six months after the high-performance computer Piz Daint was officially cleared for research, the first scientific results are in. A team of researchers from Germany, Switzerland, Italy and the USA have studied the formation of cosmic magnetic fields by simulating the development of cosmic structures such as galaxies, galaxy clusters and turbulence in the plasma that surrounds the structures. The simulations,

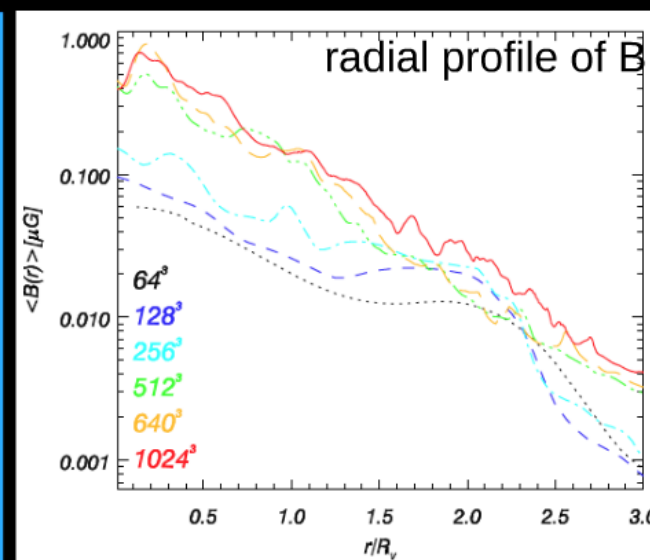
"Validation" : magnetic field in a cluster as function of resolution

(see Dolag+99,02,06; Bruggen+06, Dubois+08,Collins+10...)

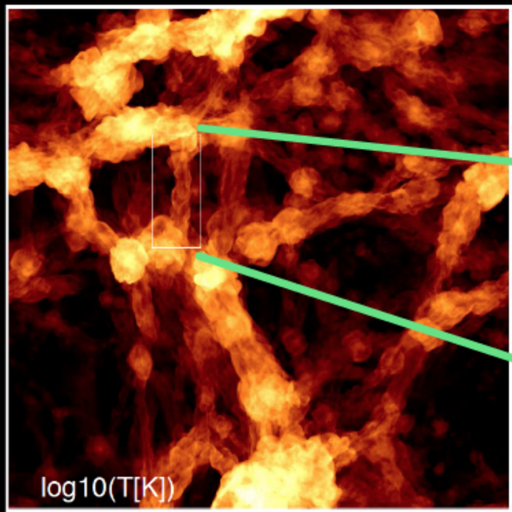


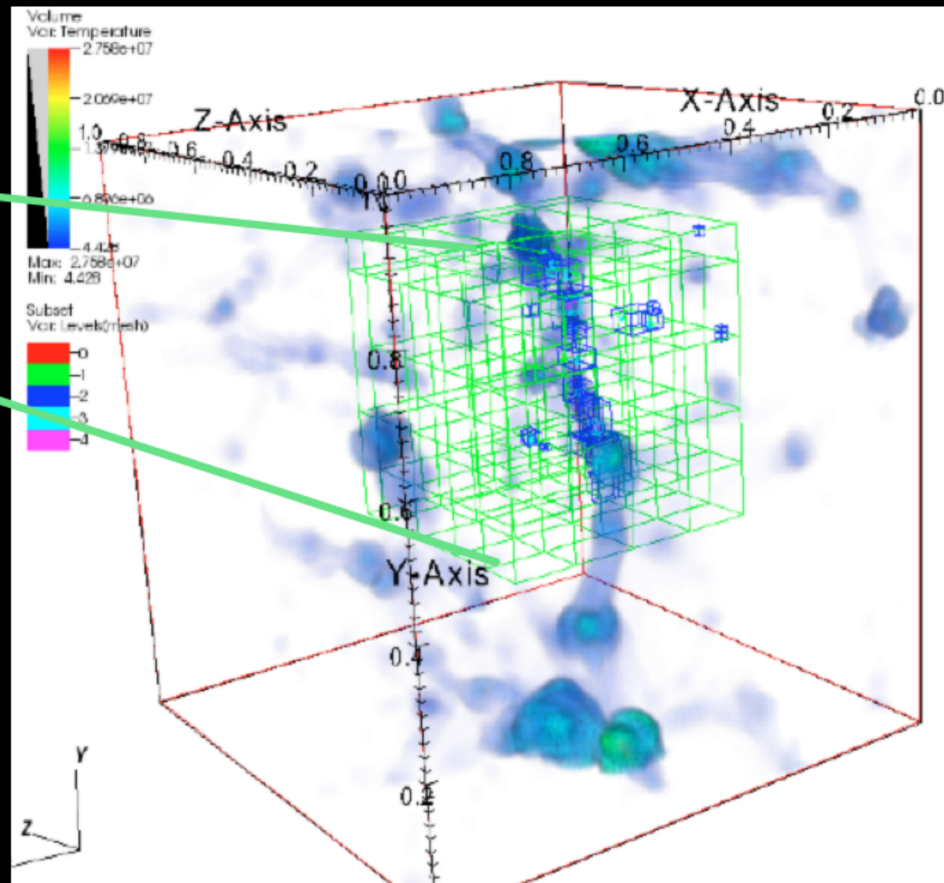
uniform grid runs from 64^3 to 1024^3 (220 to 13 kpc)



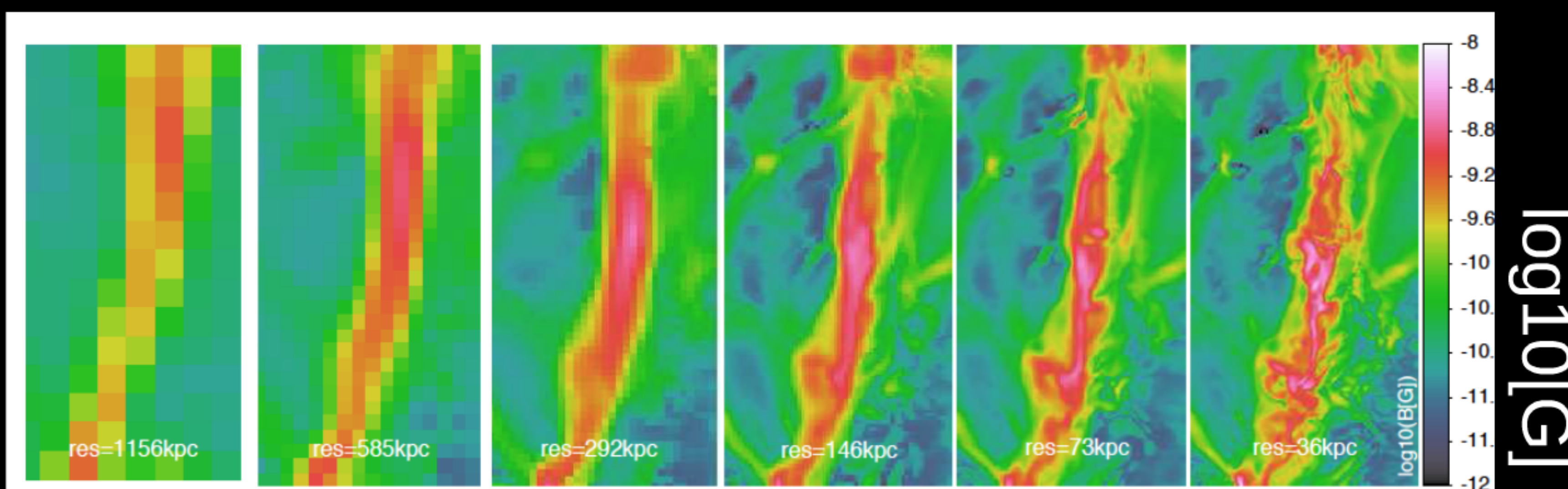


Magnetic field in a filament as function of resolution

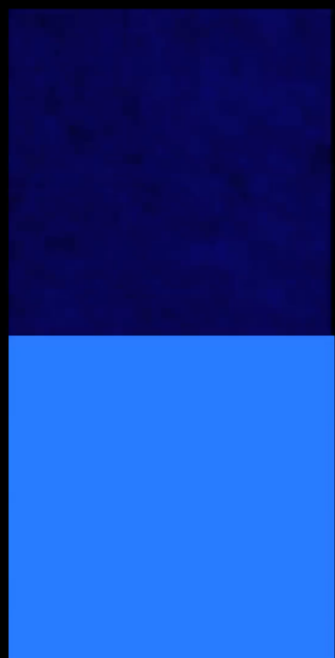


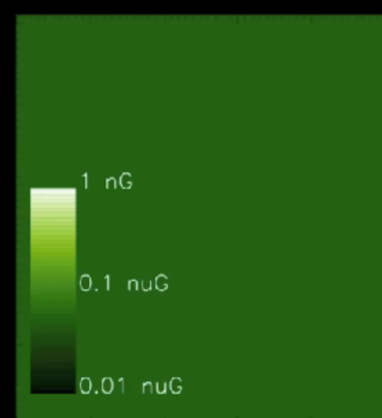


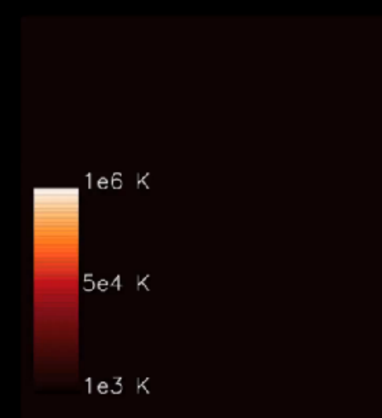
Nested initial conditions and adaptive mesh refinement for a ~20Mpc filament

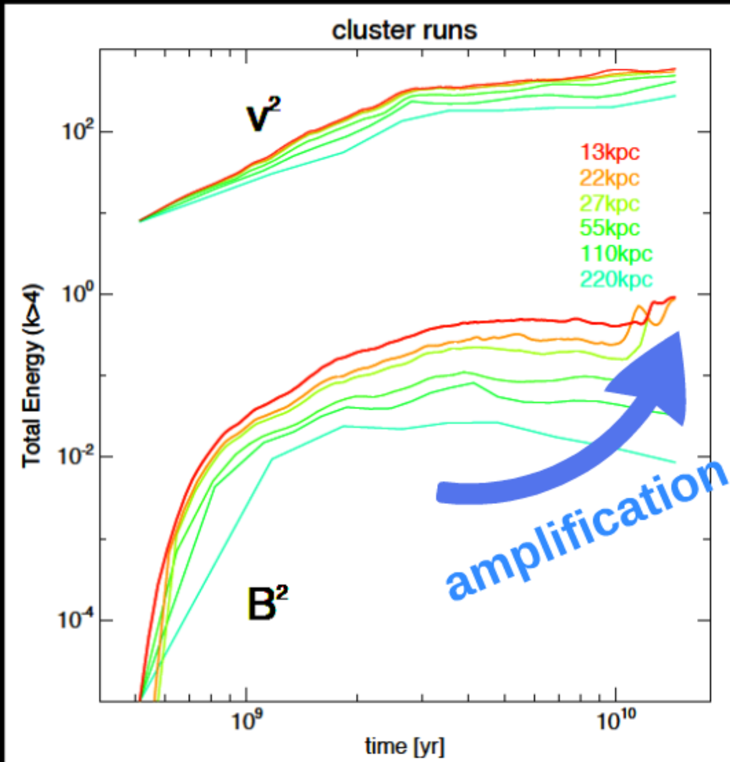


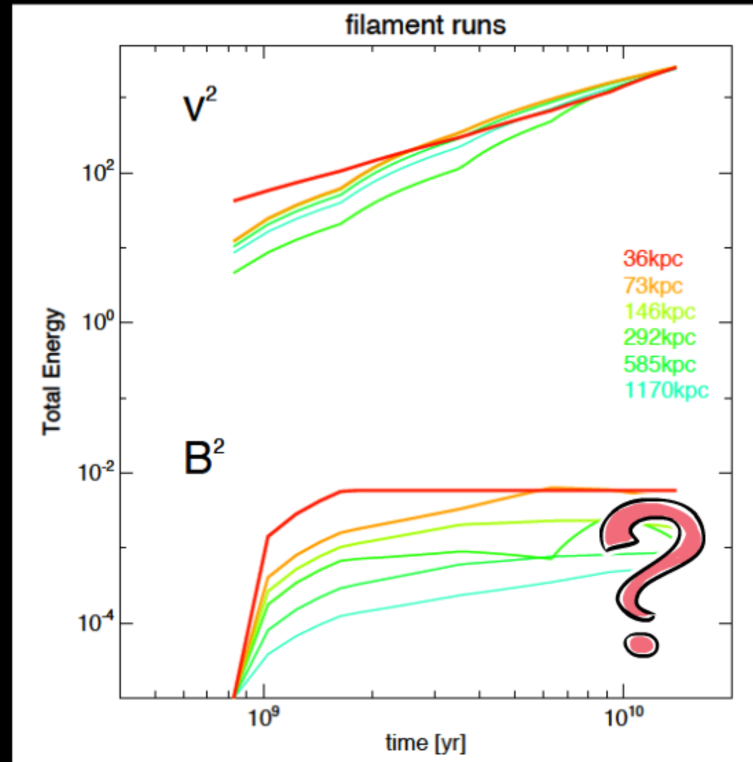
Magnetic field in a filament as function of time



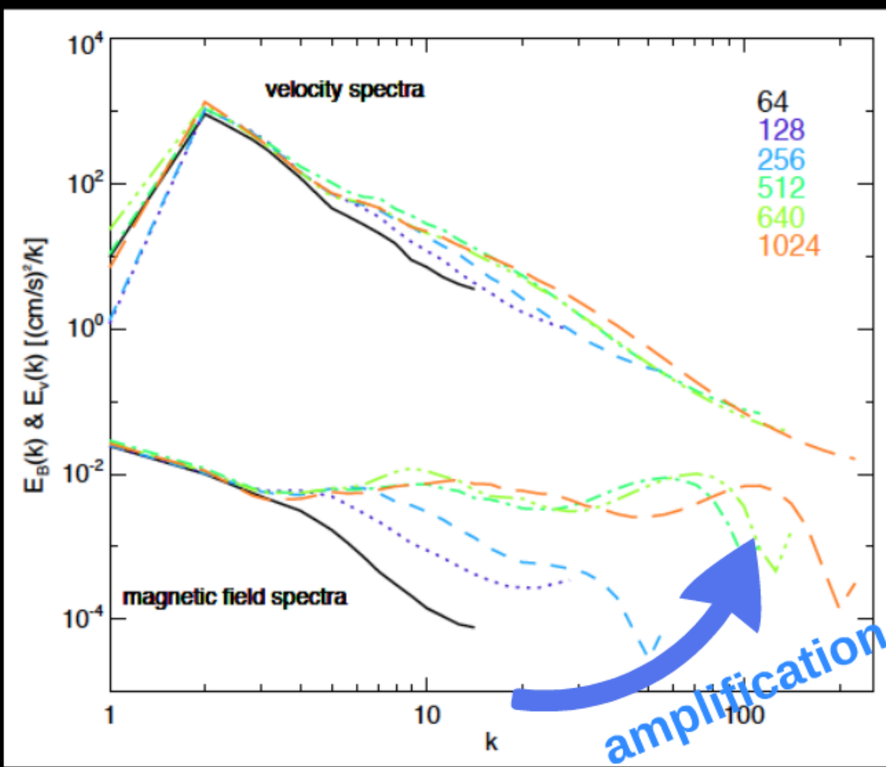


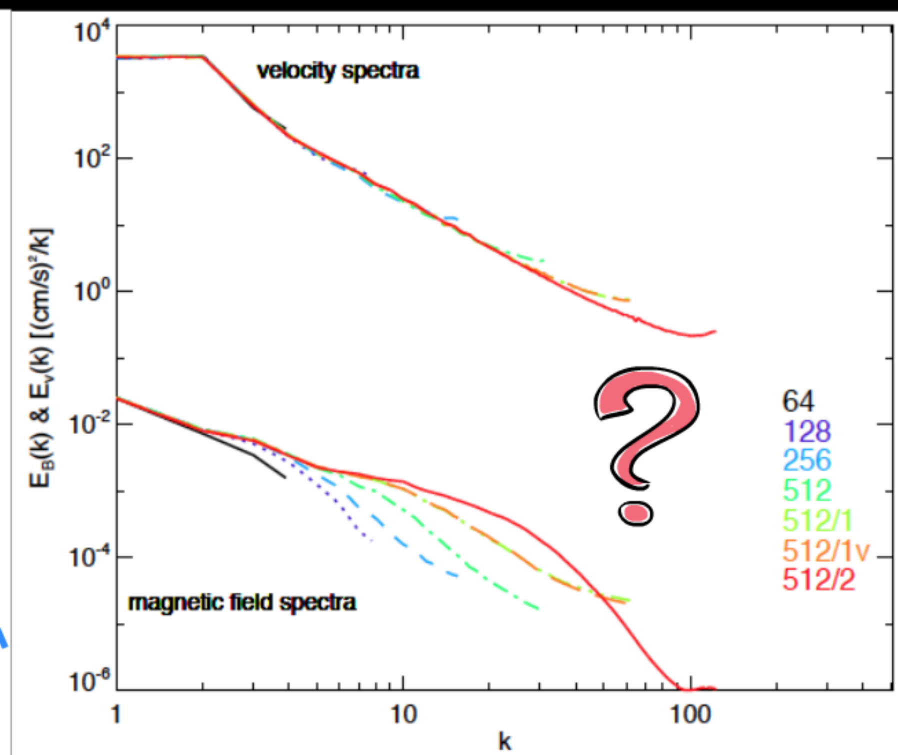






time evolution of average B-field





Spectra of v & B at different res

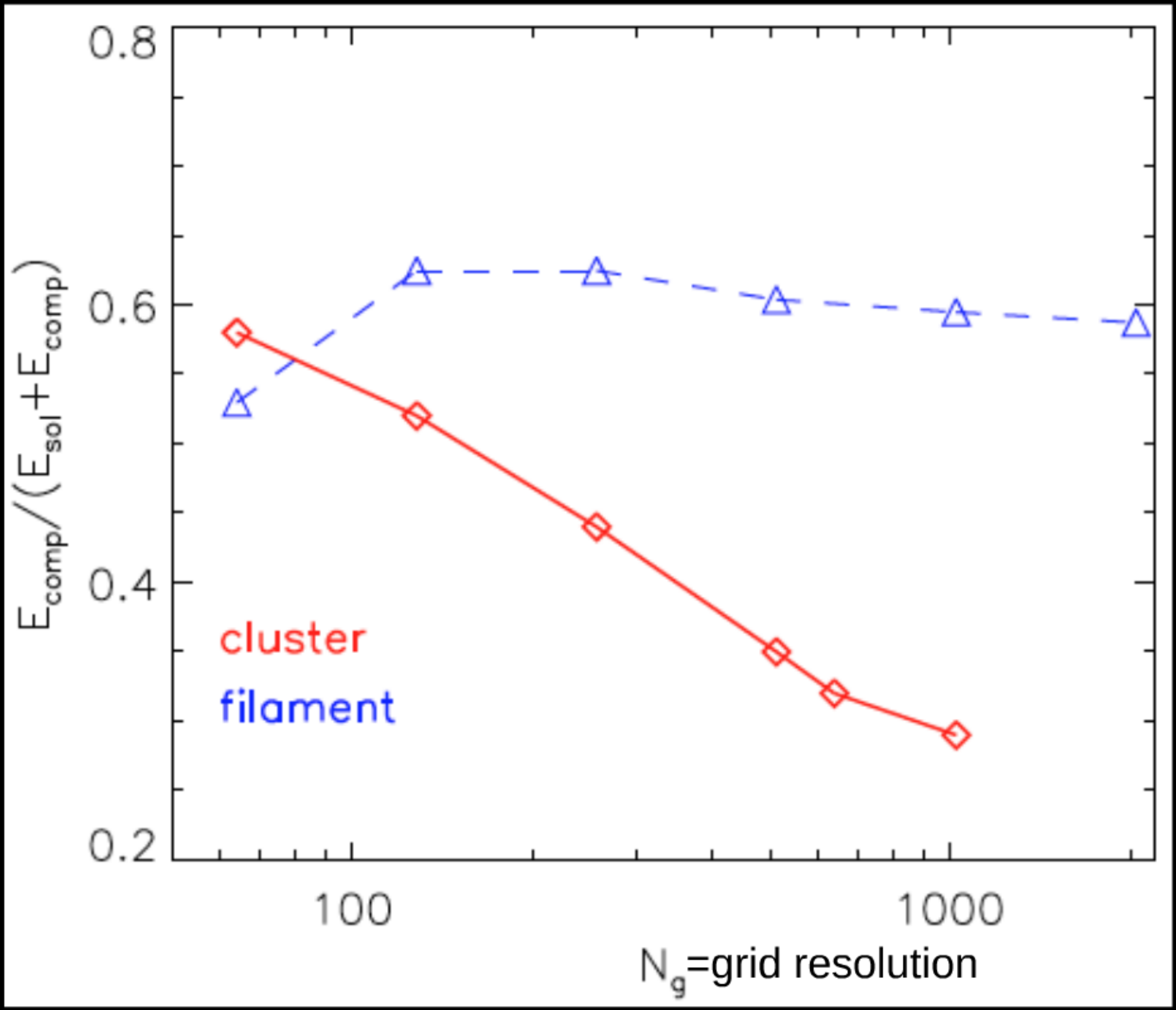
Mode decomposition of the velocity field

(see Ryu+08 and Federrath+11 for ISM studies)

div(V_sol)=0   curl(V_comp)=0

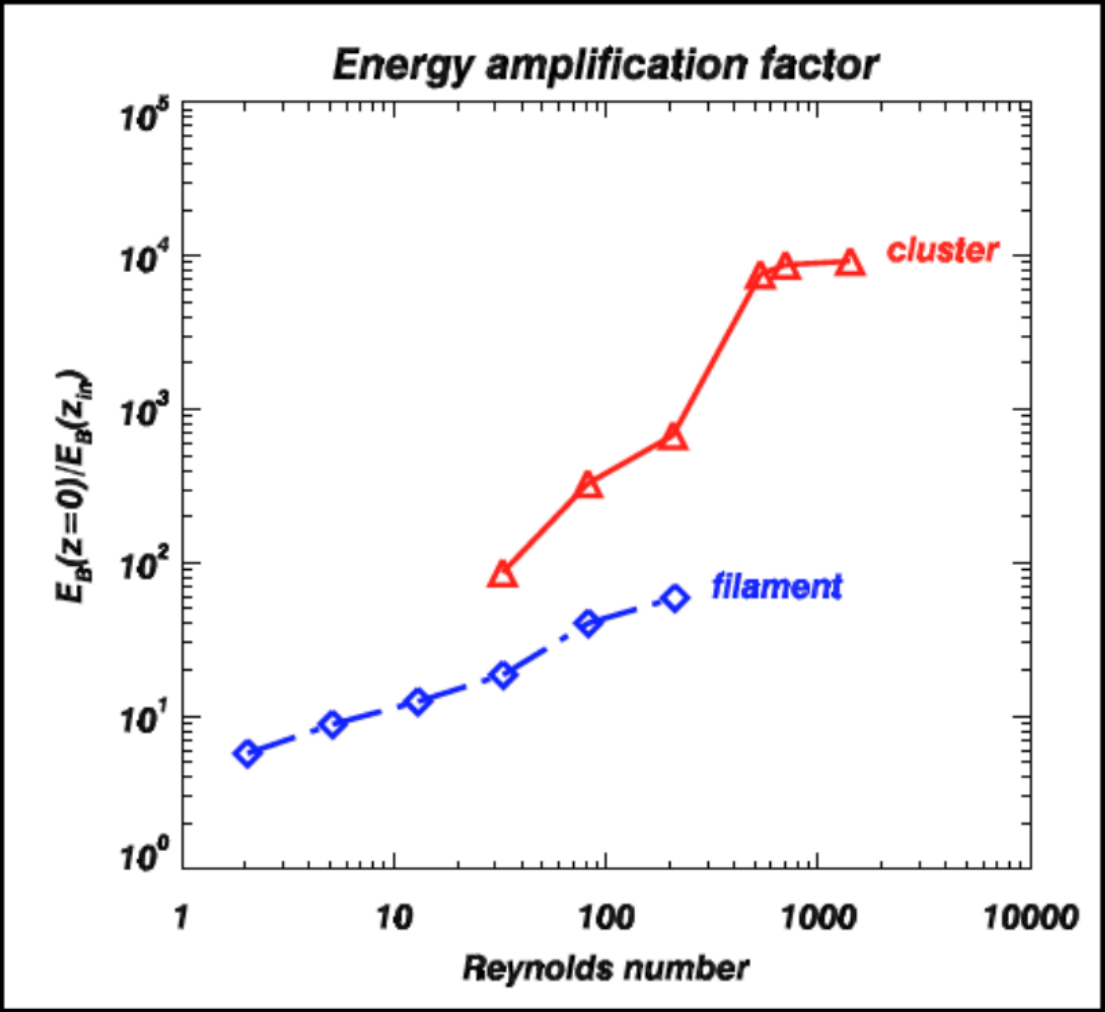
The WHIM is dominated
by compressive motions
-> inefficient dynamo

The ICM is dominated
by solenodial motions
-> efficient dynamo



Summary of B-amplification in ICM and WHIM:

- same fixed resolution does not produce a dynamo everywhere!
- clusters: >100 res.elements for Rvir to start a dynamo
- filaments: NO dynamo is observed, up to Re~200.



- the "dynamical memory" of magnetic field seeding is not erased in filaments.

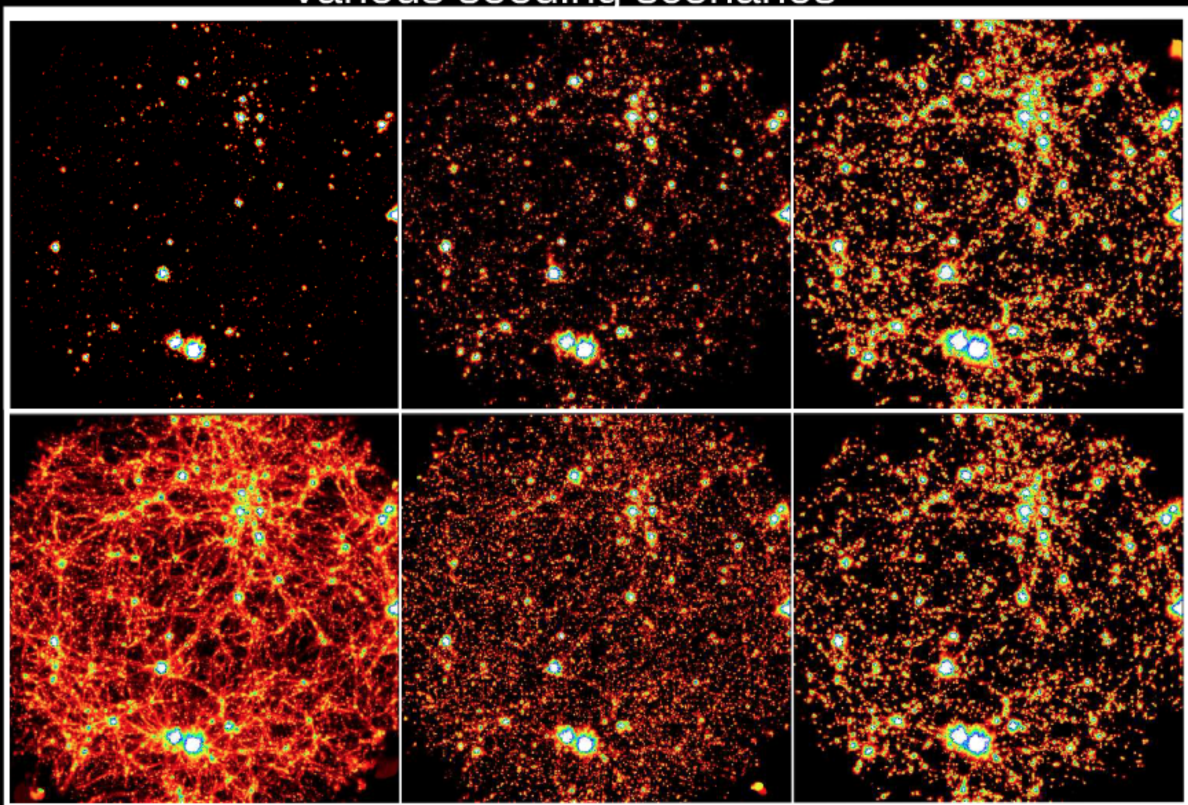
- amount of amplification at variance with SPH results

- other seeding scenarios might be at work

(see also Latif+12, Turk+12 for similar studies on mini-halos)

- ***...the primordial seeding is just one (simple) possibility***
- ***...the previous simulations probably give a lower limit***
- ***...expectations diverge oustide halos***

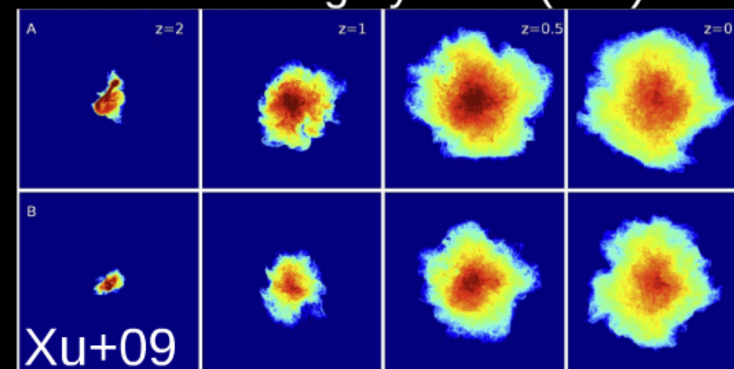
Various seeding scenarios



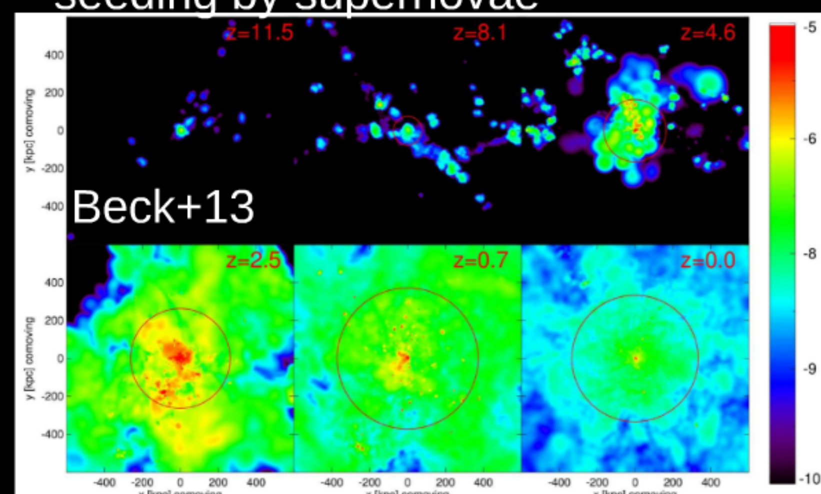
Donnert+09

..and Biermann battery (Kulsrud+99,Xu+08)
plasma flucutations (Schlickeiser 2012)..

seeding by AGN (z=2)

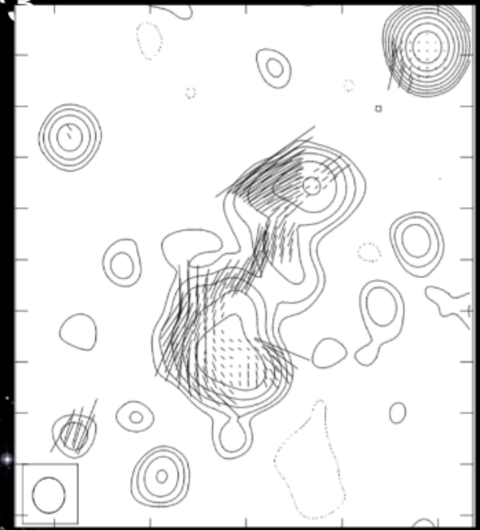


seeding by supernovae

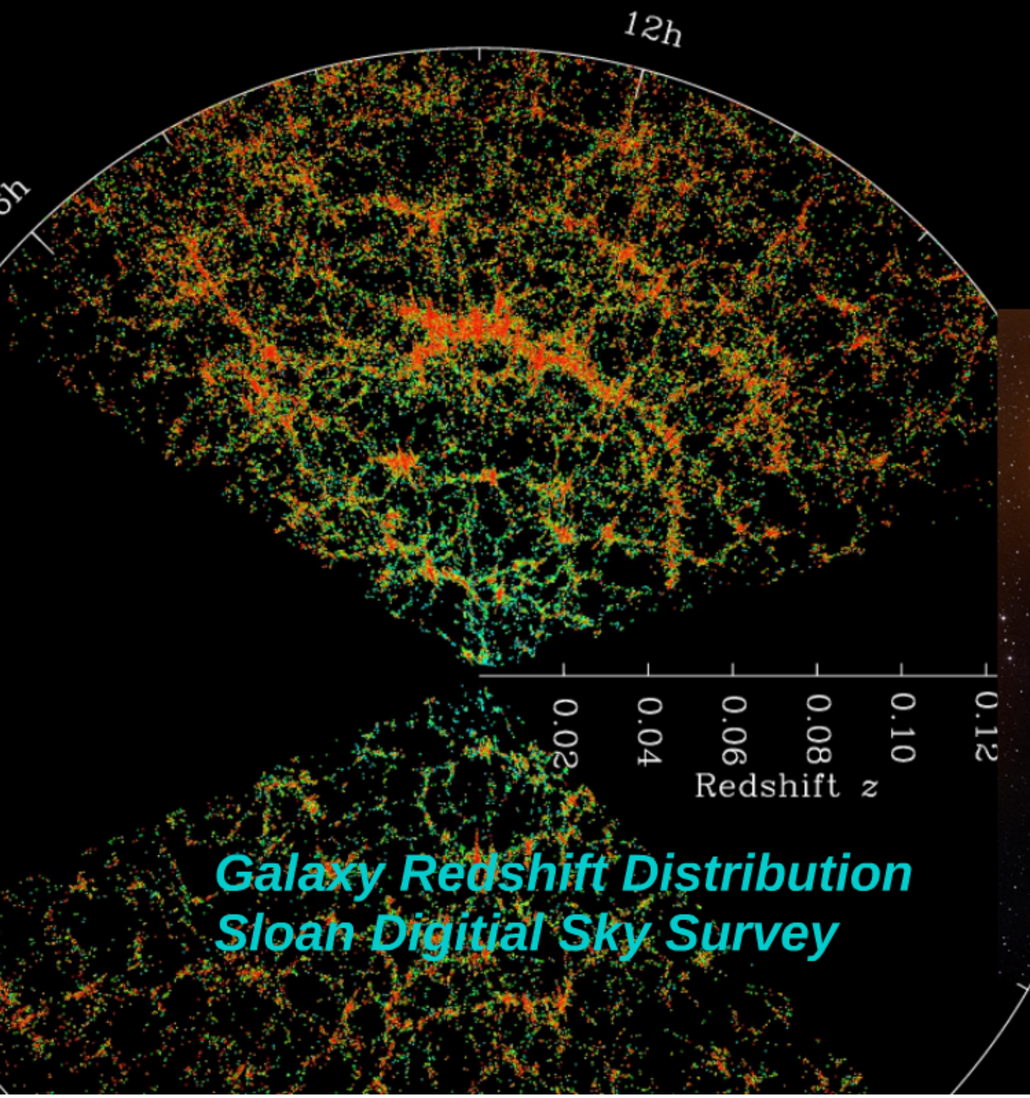


The cosmic web and filaments

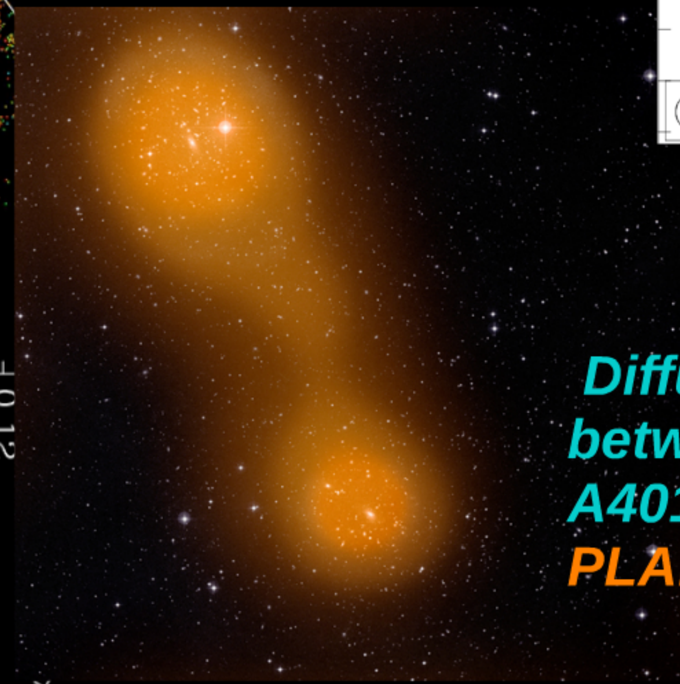
- About 90% of the total mass of the Universe in the Cosmic Web
- ~50% its mass is the form of the mildly non-linear structures of filaments
- "warm-hot intergalactic medium" 1e5<T<1e7K, n<1e-4/cm^3



large-scale radio emission outside clusters (Giovannini+10, Farnsworth+13)



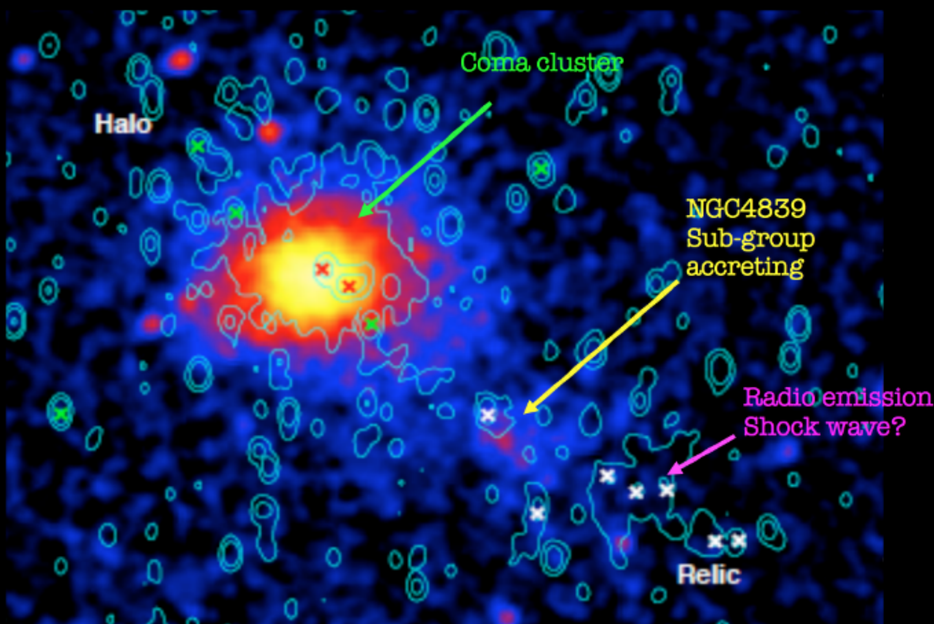
Galaxy Redshift Distribution Sloan Digitial Sky Survey



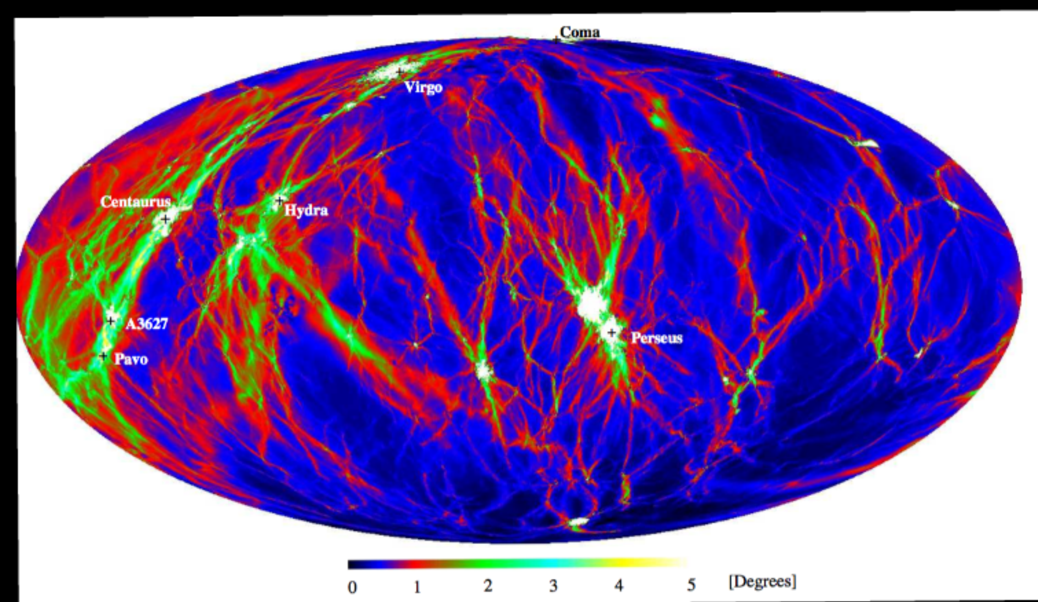
Diffuse SZ signal between A399 and A401 with PLANCK (2011)

Observable effects of large-scale B-field

- Synchrotron emission   power   ~ ∫ nCRe x B^2   (B<3.2mG)
- Faraday Rotation   RM   ~ ∫ ngas x B(parallel)
- Deflection of UHECR   deflect.   ~ ∫ Z/E x B(perpendic.)



Faraday Rotation along the SW sector of COMA (Bonafede,FV+13)
RM grids : Taylor+10, future: SKA



Deflection of UHECRs by extragalactic mag.field (Dolag+03, Sigl+03, Das+08..)

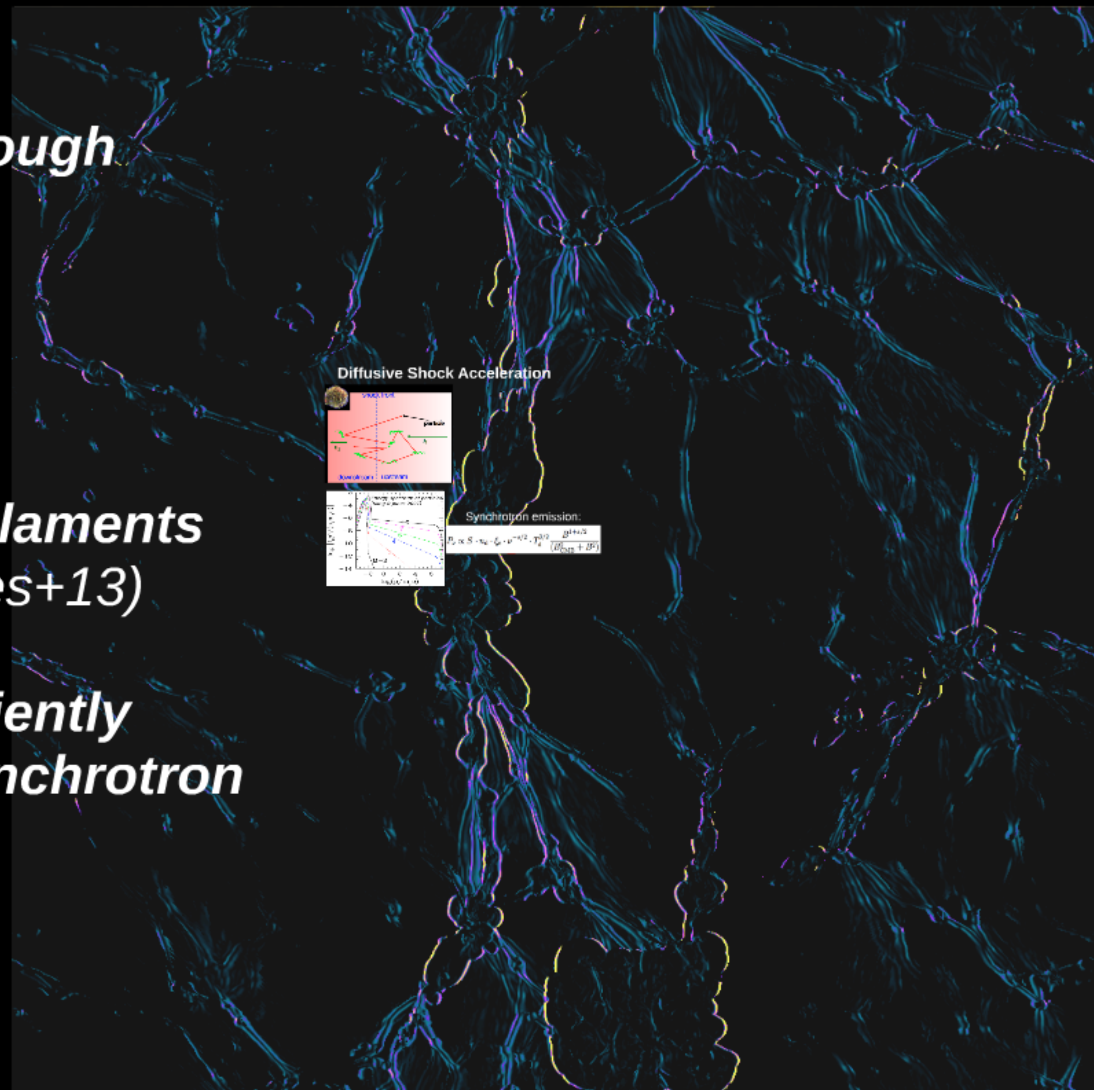
Can we detect the cosmic web in radio?

FV, Ferrari, Bonafede,Bruggen,Gheller,Braun,Brown AASKA14

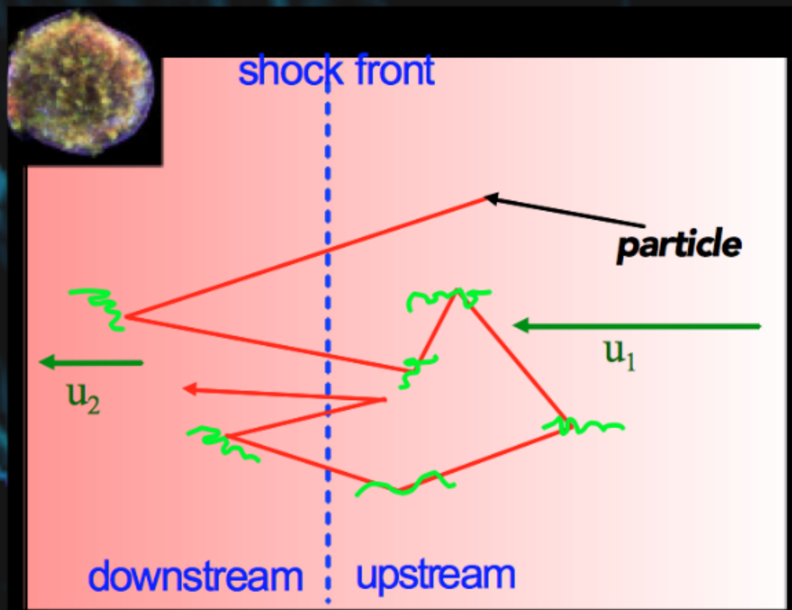
- ***Structure formation happens through supersonic matter accretions***
(Sunyaev & Zeldovich 1976)

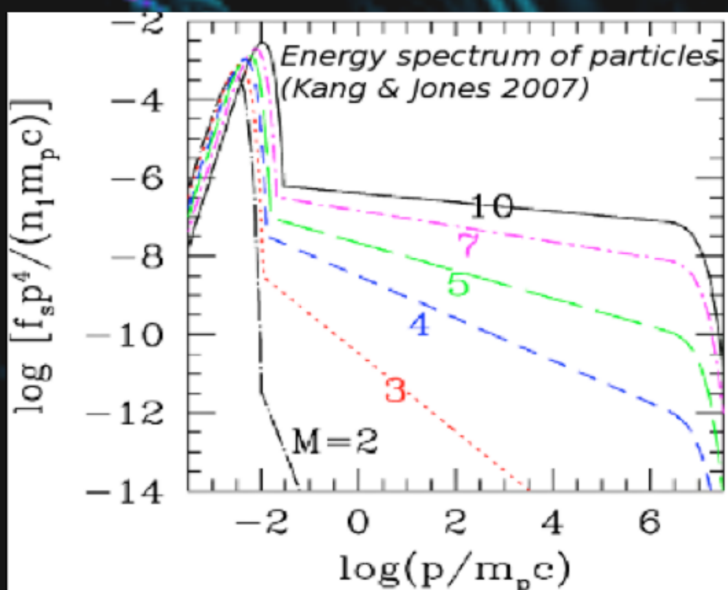
- ***Strong shocks (M>>10) at the periphery of structures, including filaments***
(Ryu+03,Pfrommer+07,FV+09,Planelles+13)

- ***Relativistic particles can be efficiently accelerated there and radiate via synchrotron***
(Hoeft+08,Skillman+08,13)



Diffusive Shock Acceleration





Synchrotron emission:

$$P_\nu \propto S \cdot n_\mathrm{d} \cdot \xi_\mathrm{e} \cdot \nu^{-s/2} \cdot T_\mathrm{d}^{3/2} \frac{B^{1+s/2}}{(B_\mathrm{CMB}^2 + B^2)}$$

Can we detect the cosmic web in radio?

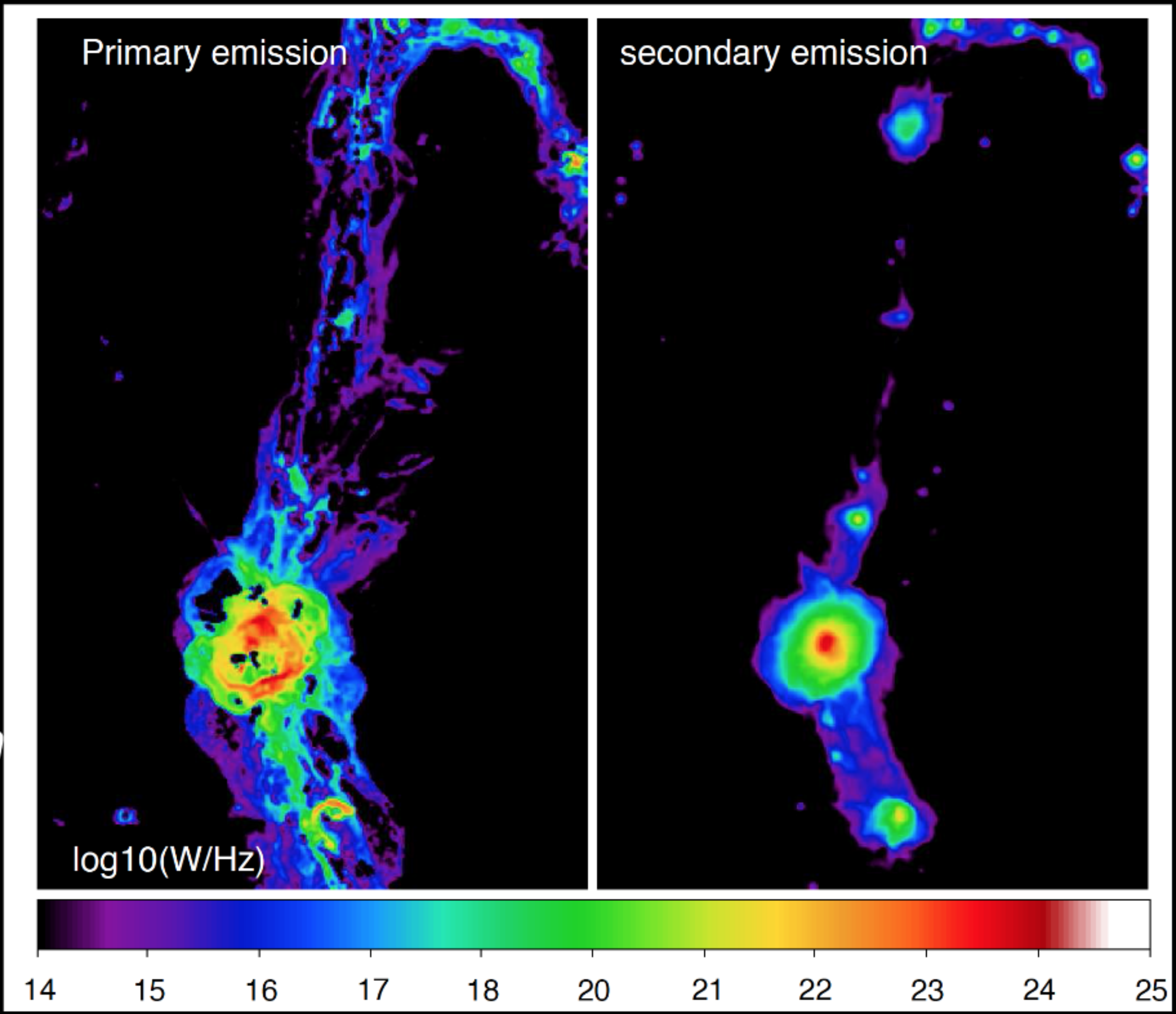
FV, Ferrari, Bonafede,Bruggen,Gheller,Braun,Brown AASKA14

This first step:
- ***NO MHD simulations***
- ***2-fluid prescripton for relativistic protons***

1) "primary emission" from shock accelerated electrons
(e.g. Hoeft & Bruggen 07)
-post-proc. shock finder
-shock efficiency from DSA
-Kep=0.01%

+

2) "secondary emission" from electron released in hadronic collisions (e.g. Dolag & Ensslin 00)
-CRs from our 2-fluid model



Assesment of detectability with various SKA instruments (Phase 1 - 2020+)

-2yr survey or 1000 hr exp.

-baseline filtering

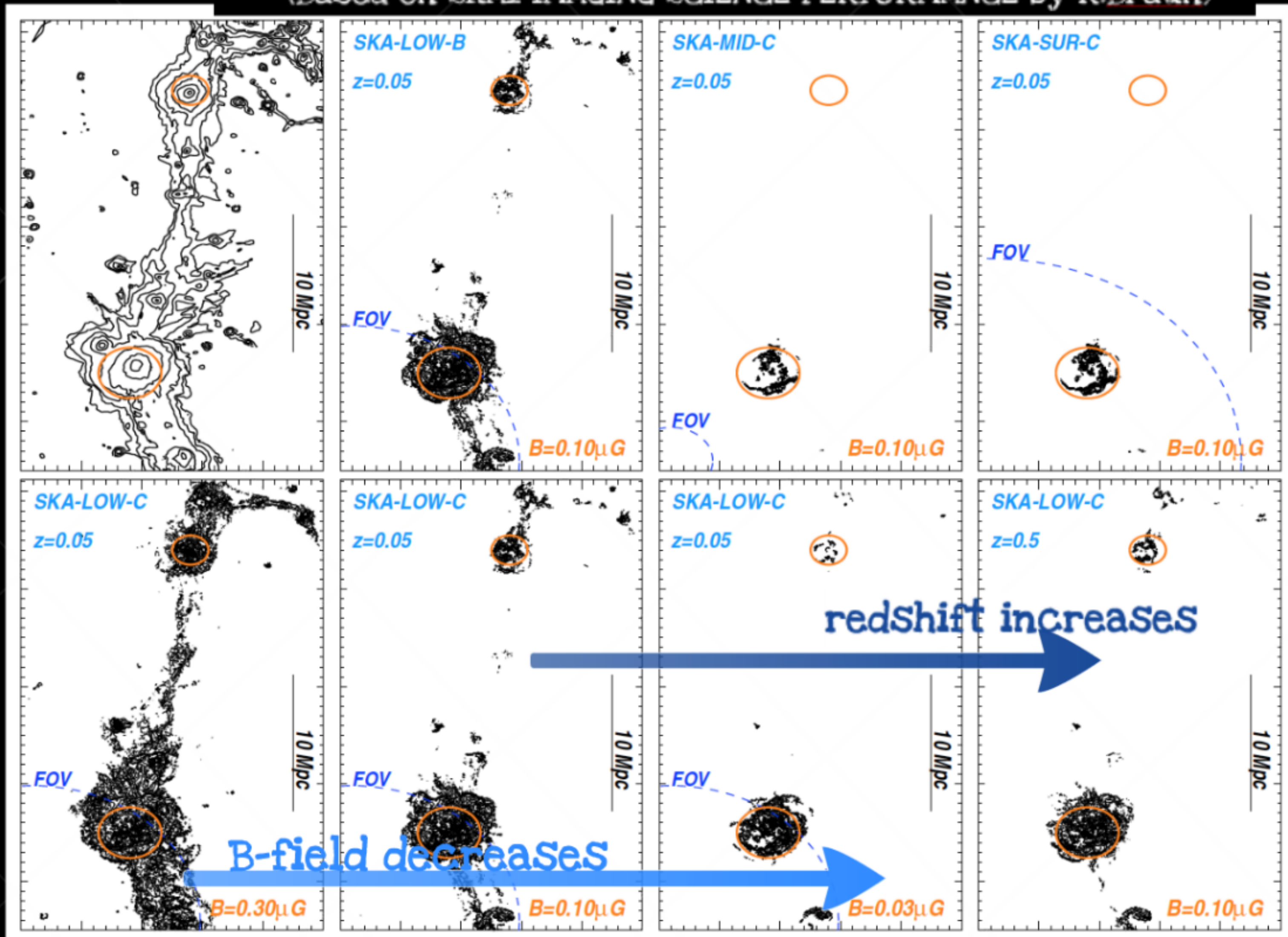
- FGs are removed

- no point sources.

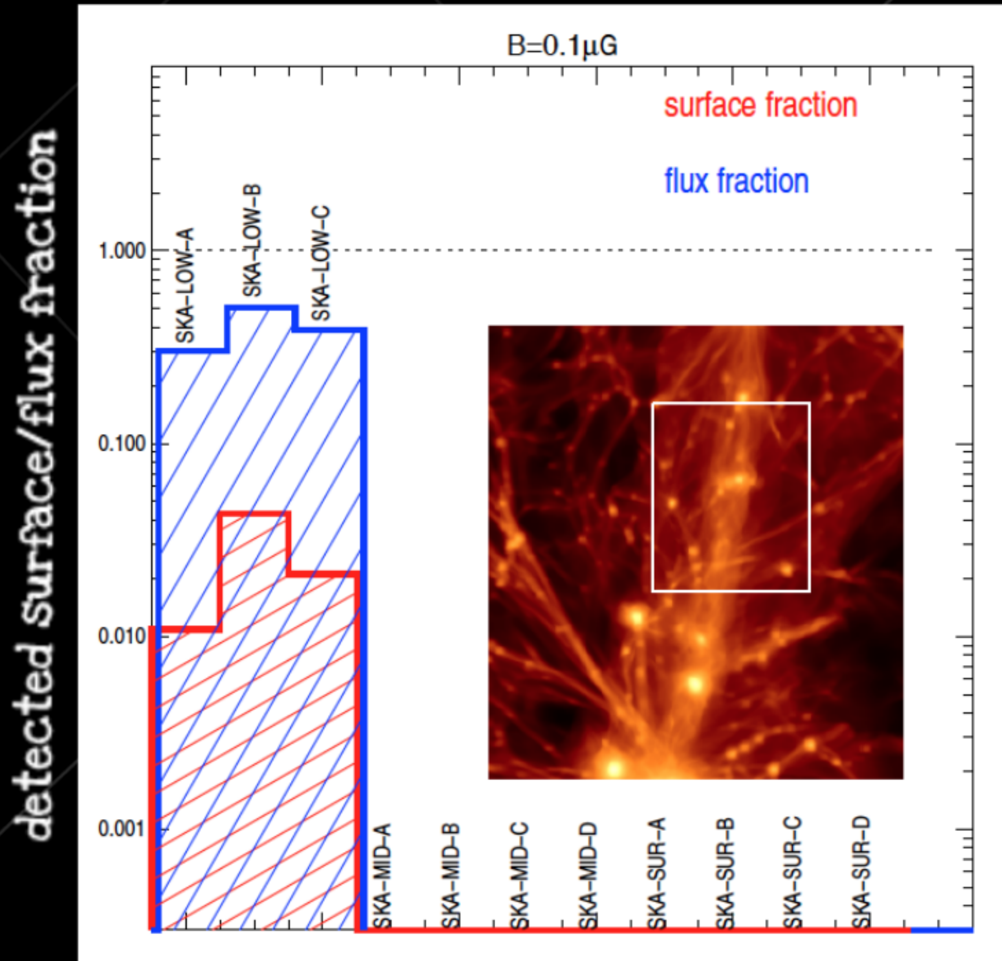
- LOFAR as a "prior"

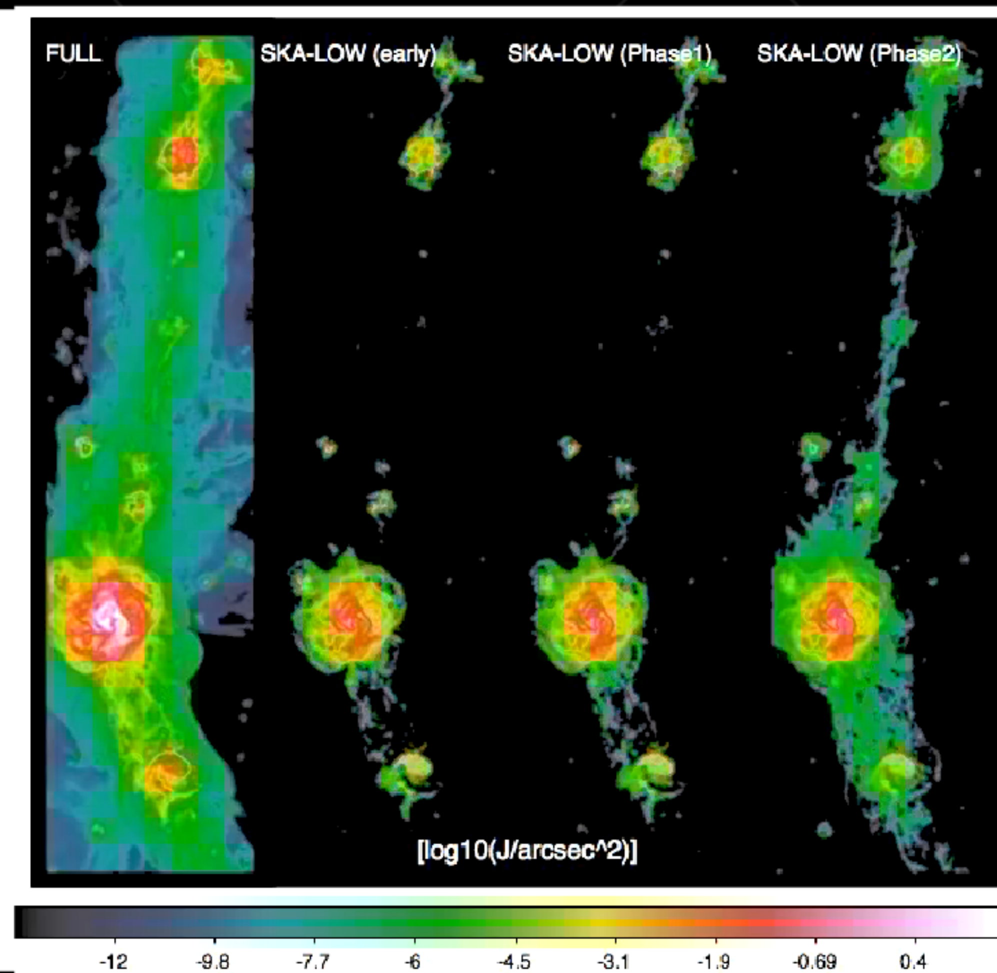
array	configuration/strategy	frequency [MHz]	beam size [arcsec]	field of view [degrees^2]	min. baseline [m]	sensitivity 1 [μJy/beam]	sensitivity 2 [μJy/arcsec^2]
SKA-LOW-A	full res+conf., survey	110	6	8	45	5.5	0.134
SKA-LOW-B	full res+conf,1000 hr	300	3	8	45	0.5	0.0490
SKA-LOW-C	full res+conf., survey	300	10	8	45	9	0.0794
SKA-MID-A	1000hr	1400	0.5	0.49	15	0.09	0.317
SKA-MID-B	2 years	1400	0.5	0.49	15	5.8	20.475
SKA-MID-C	1000 hr+tapering	1400	10	0.49	15	0.14	0.001
SKA-MID-D	2 years+tapering	1400	10	0.49	15	8.8	0.077
SKA-SUR-A	1000hr	1200	1.0	18	15	0.4	0.353
SKA-SUR-B	2years	1200	1.0	18	15	3.8	3.353
SKA-SUR-C	1000hr+tapering	1200	10	18	15	0.5	0.004
SKA-SUR-D	2years+tapering	1200	10	18	15	4.9	0.043

(Based on SKA1 IMAGING SCIENCE PERFORMANCE by R.Braun)



Detectability with different SKA instruments





- SKA SUR/MID : only 1-2 filaments per FOV in 1000hr and 0.4<z<0.5.
- SKA LOW: chance of detection for z<0.2-0.3 even in survey mode
- Phase 1(2020+): only brightest knots can be detected

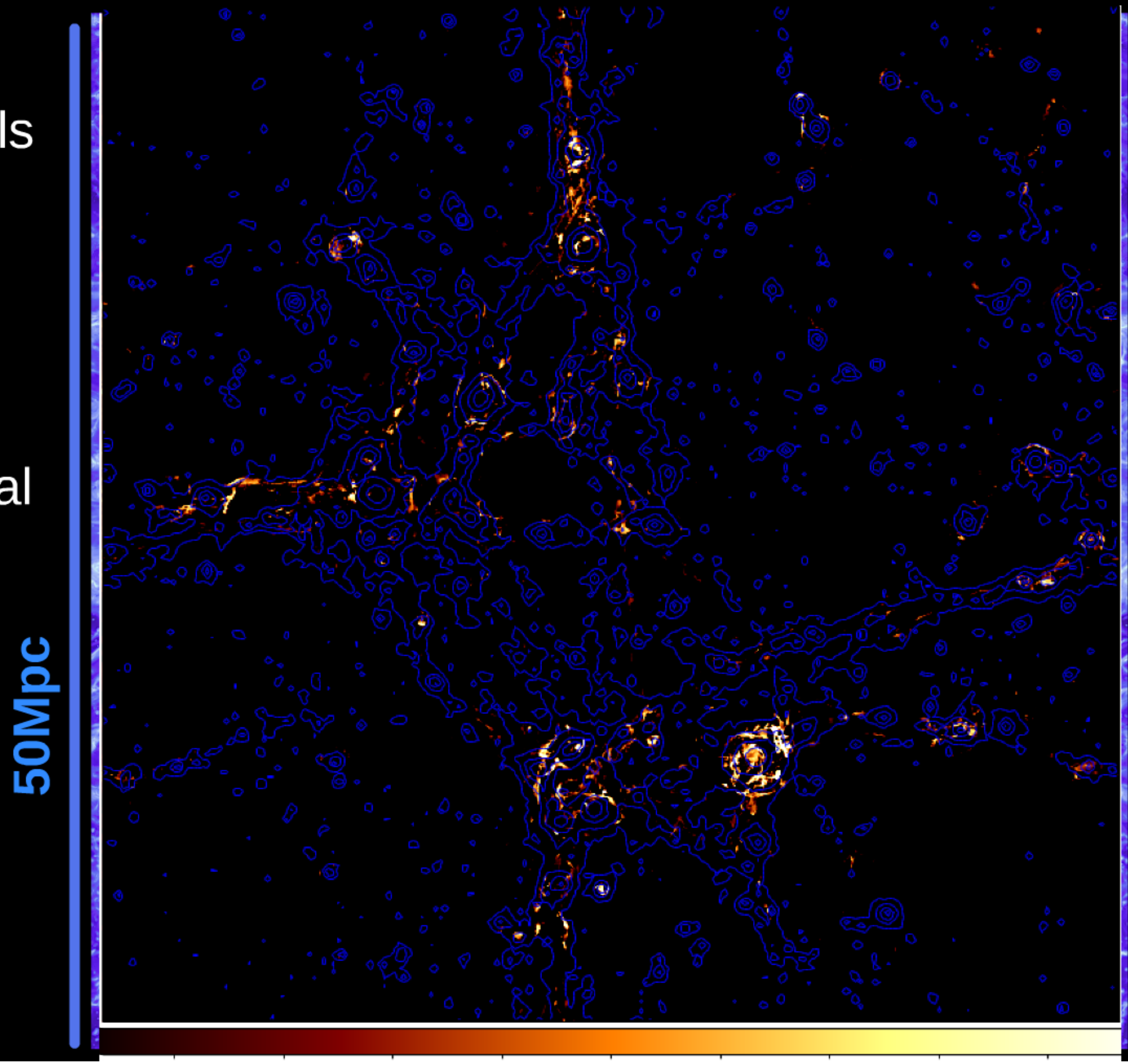
Phase 2(2030+): 10% of the cosmic web can be detected

Follow-up(1): surveys of larger volume with MHD runs

- 2400^3 cells & DM particles

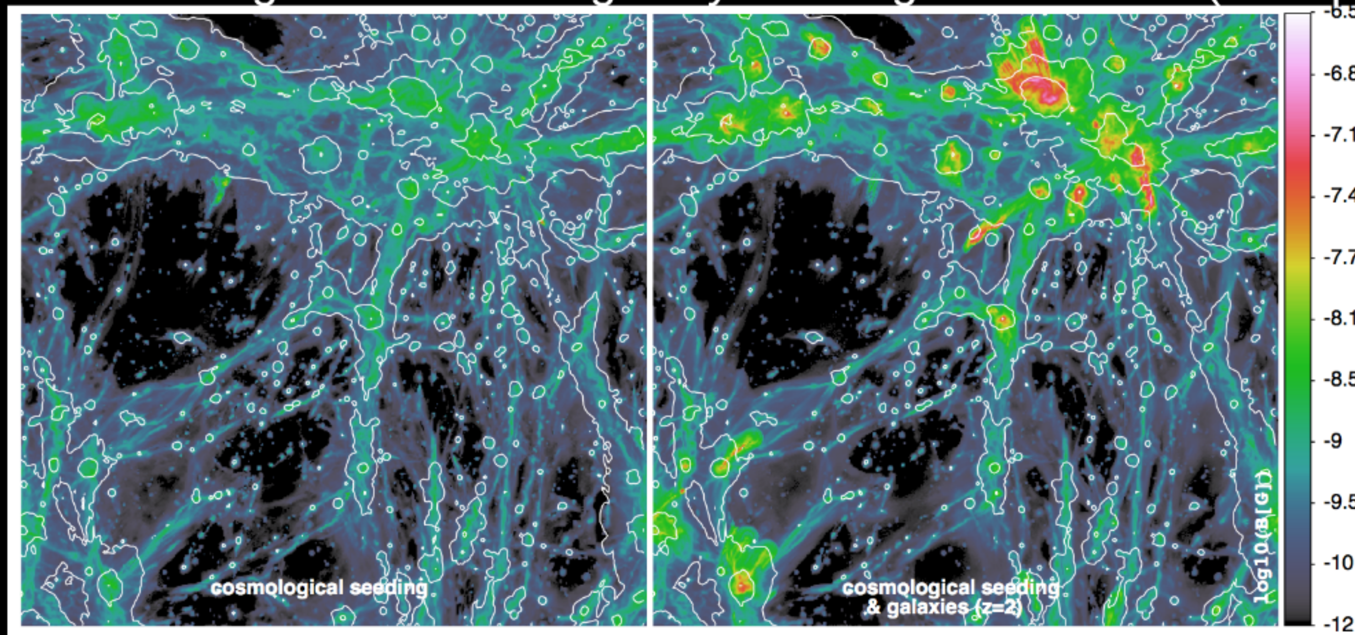
- res.20kpc

-cosmological seeding



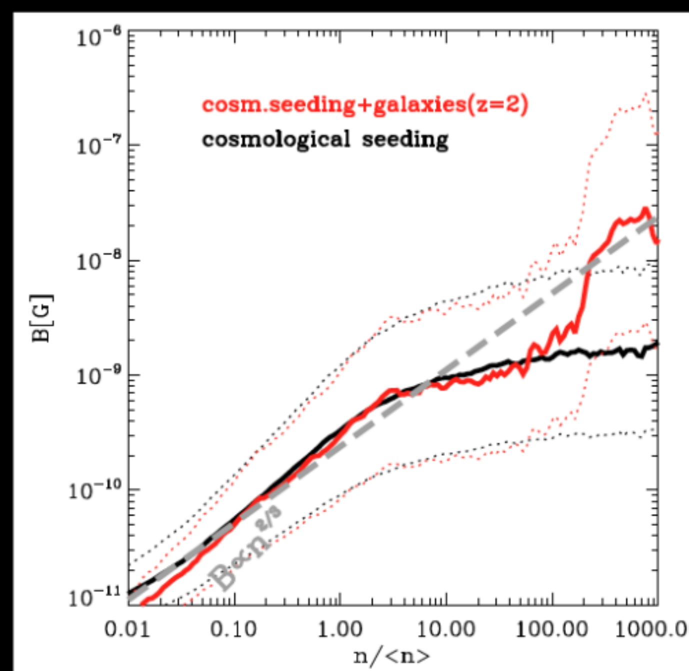
Follow up(2): additional seeding by galaxies (i.e. stripping)

cosmological vs cosm.+galaxy seeding   1200^3 for (25 Mpc)^3



-Only a small impact, limited to >100 <n>

- filaments not affected

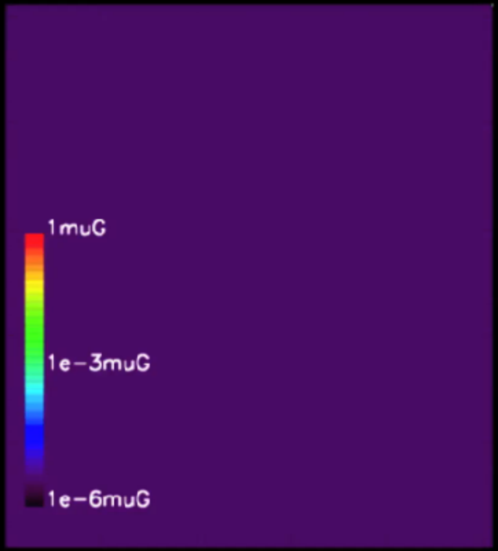


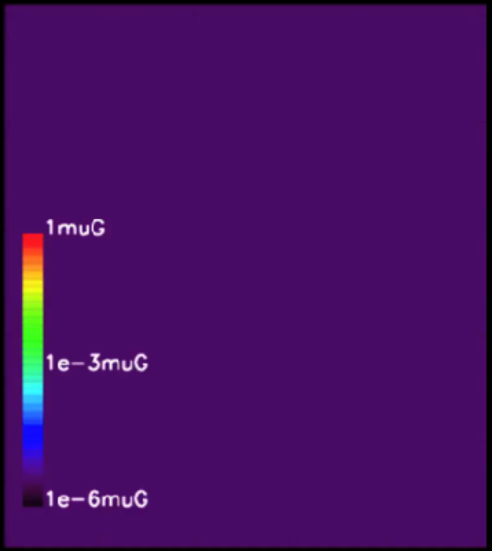
Follow up(3): additional seeding by AGN -> big difference!

MHD+CSF

MHD+CSF+AGN

Model:
- fixed grid (80kpc)
- MHD
- Cloudy (metal dep.) cooling
- star formation (Cen & Ostriker)
- thermal star feedb.
- thermal AGN feedb.+ 1% energy goes into B

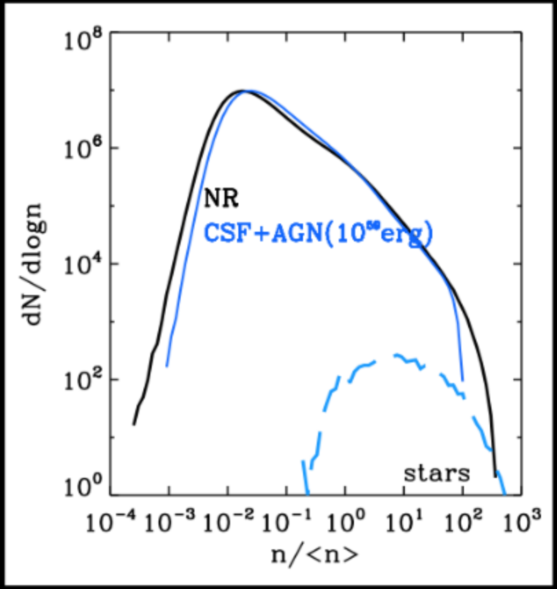


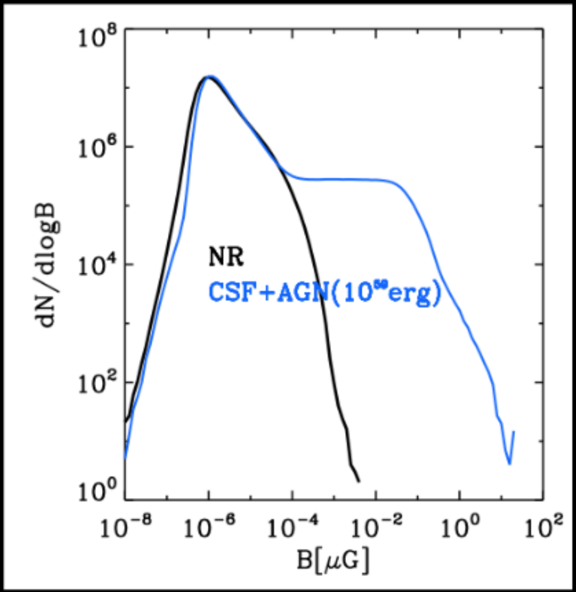


- big effects in halos & filaments

- unknowns must be tuned against SFR observables

- non-trivial behaviour with resolution

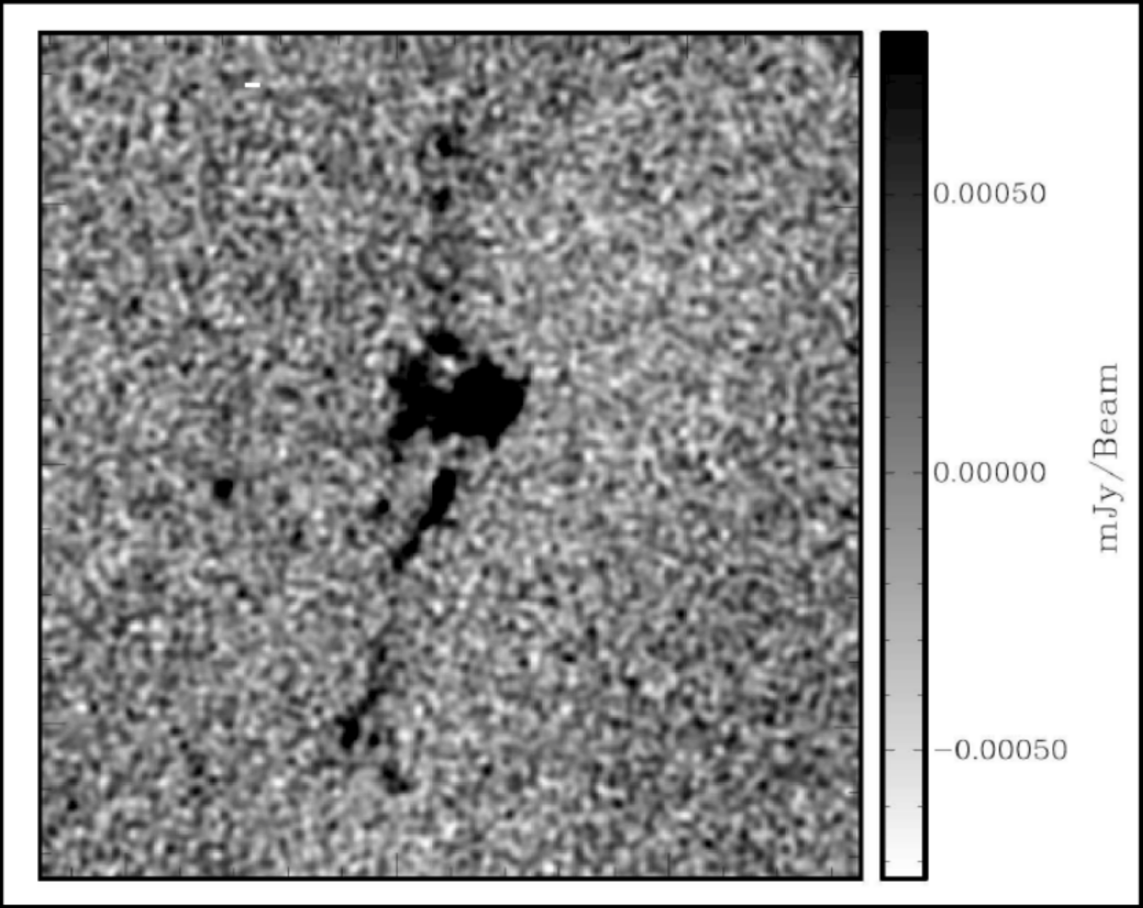




work in progress...

Summary of detectability of the cosmic web with SKA

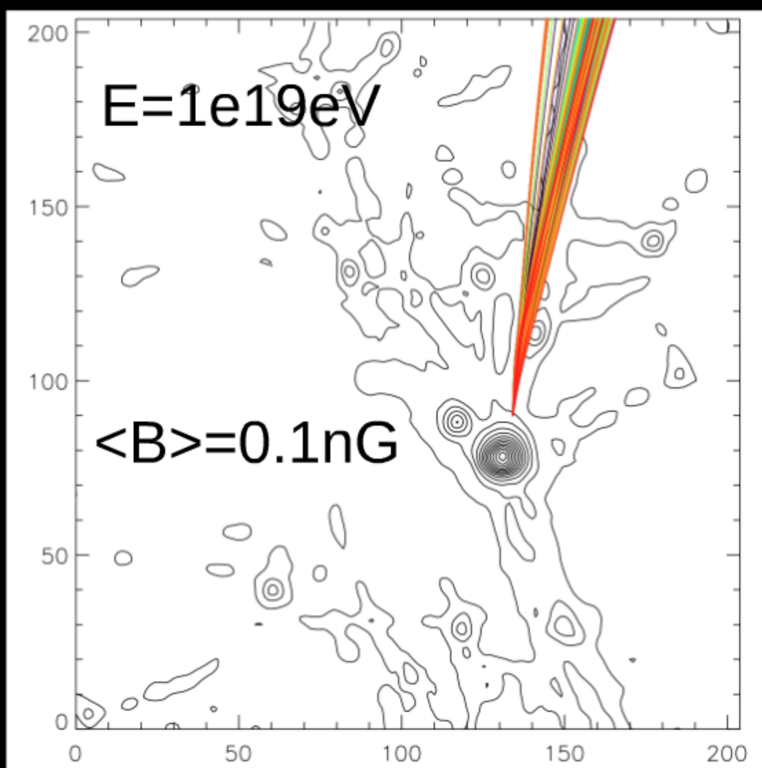
- if DSA at work, synchrotron radio emission limits B^2
- "cosmological seeding": nearly no hope of detection with SKA
- additional seeding(s): brightest knots detectable if B>0.05-0.1muG
- low frequencies <300MHz (SKA-LOW, LOFAR) are best to to sample short baselines
- test with the "SKA simulator" are ongoing (by R.Braun)

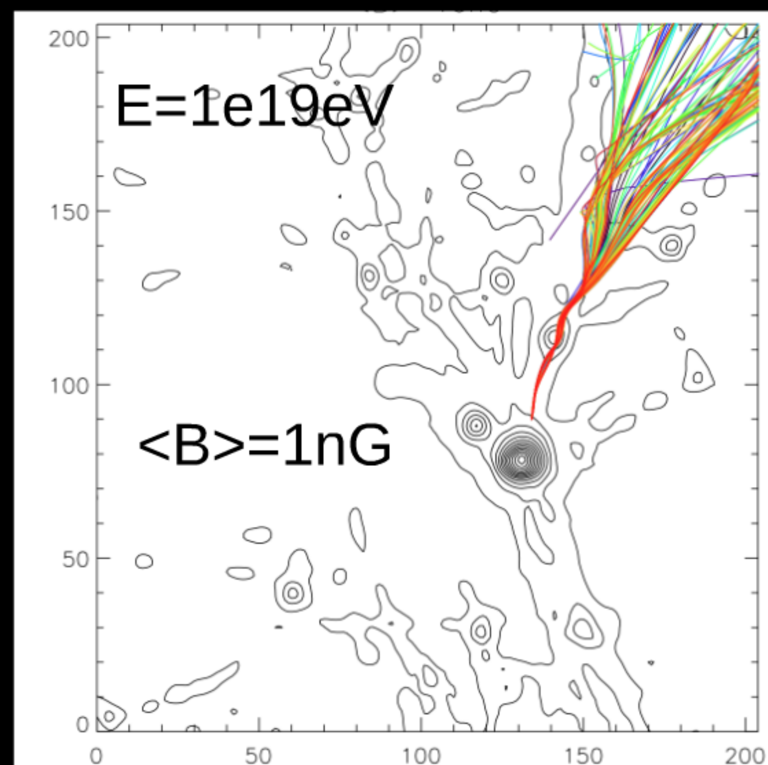


(simulated 2000hr observation of our filament by R. Braun)

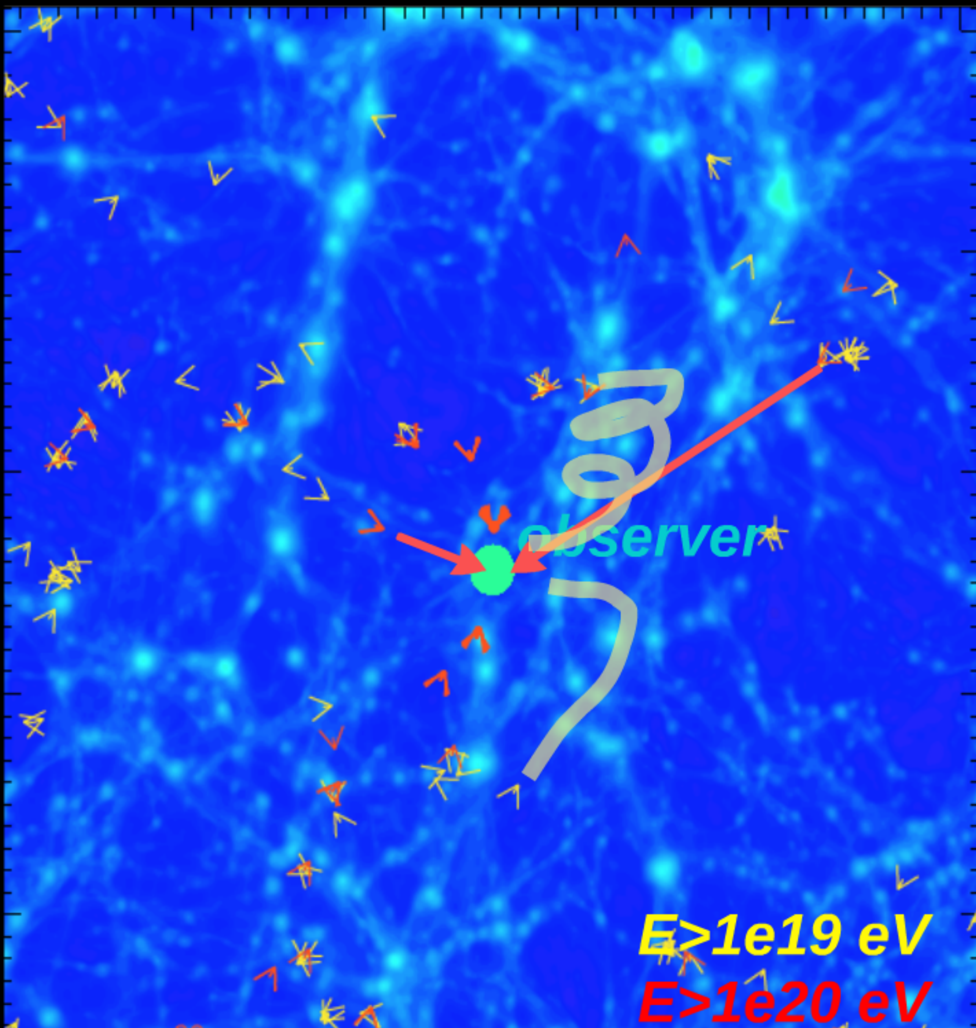
The study of UHECRs as a tool to study cosmic magnetism
Stefan Hackstein - Bachelor Thesis

- input: 3D MHD simulations (different seeding)
- CRPropa 3 (Sigl et al.2012) for the propagation of UHECRs
  - Energy range: 1e17-1e21 eV
    - deflection by extragalactic mag.fields
      - photo-pion production -> GZK cutoff
        - Z=1 (only protons)

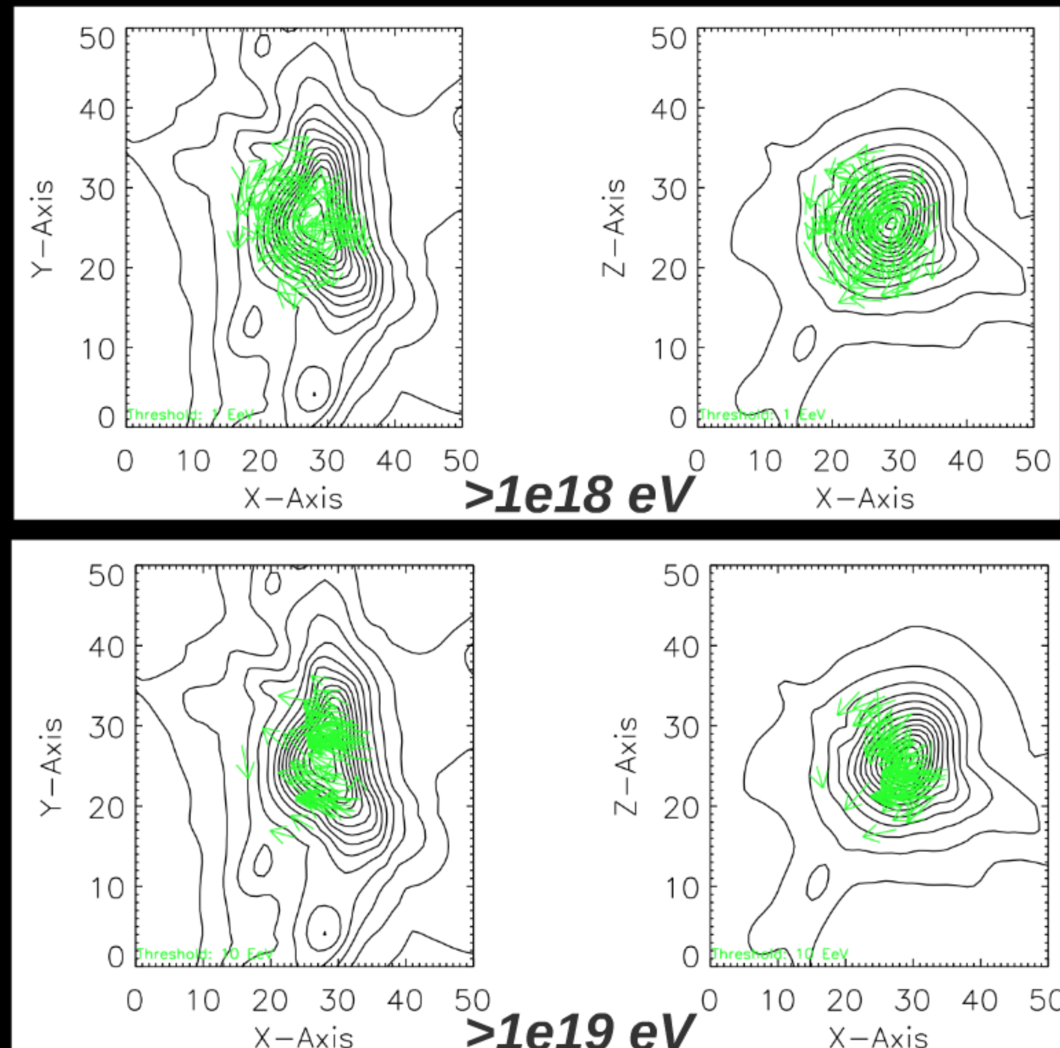


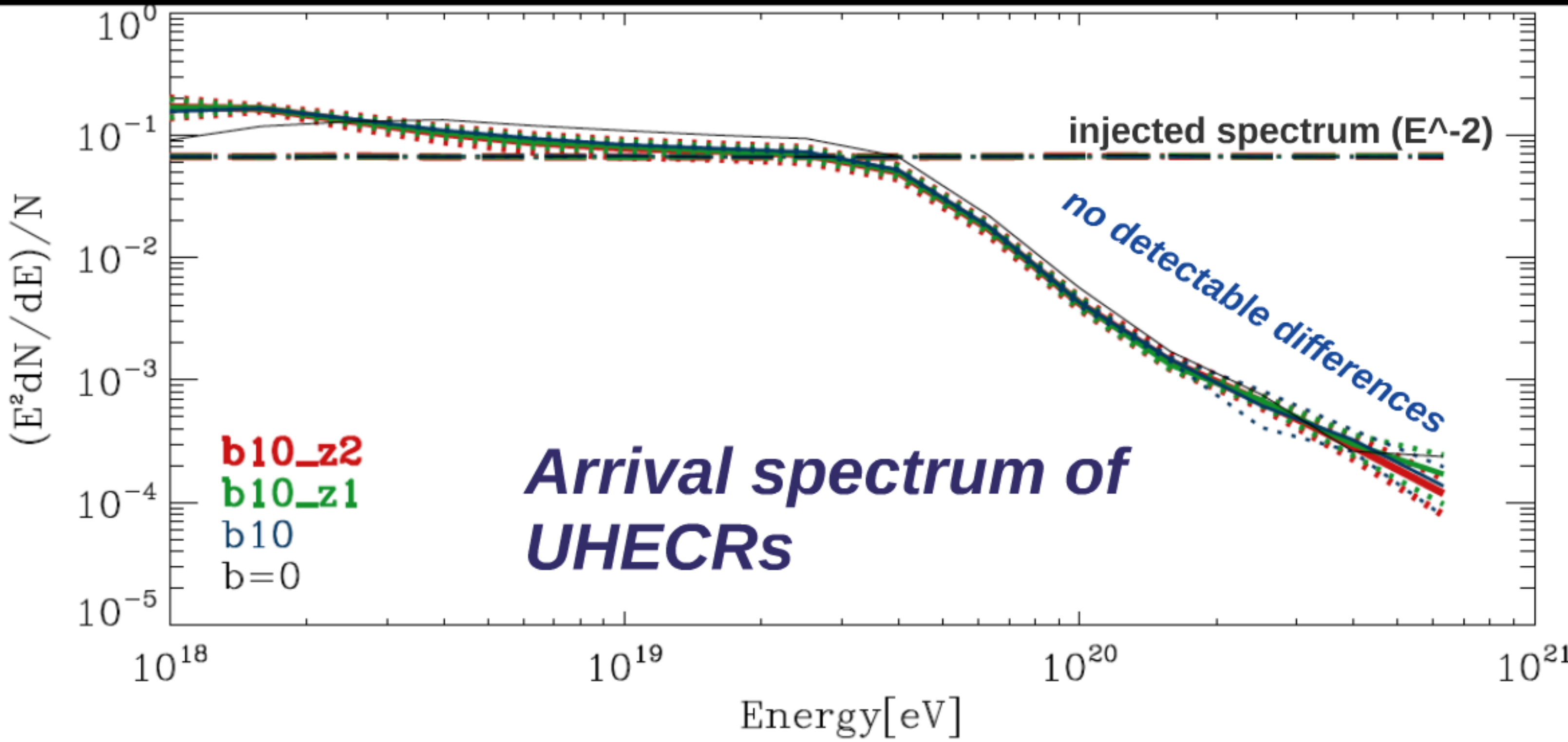


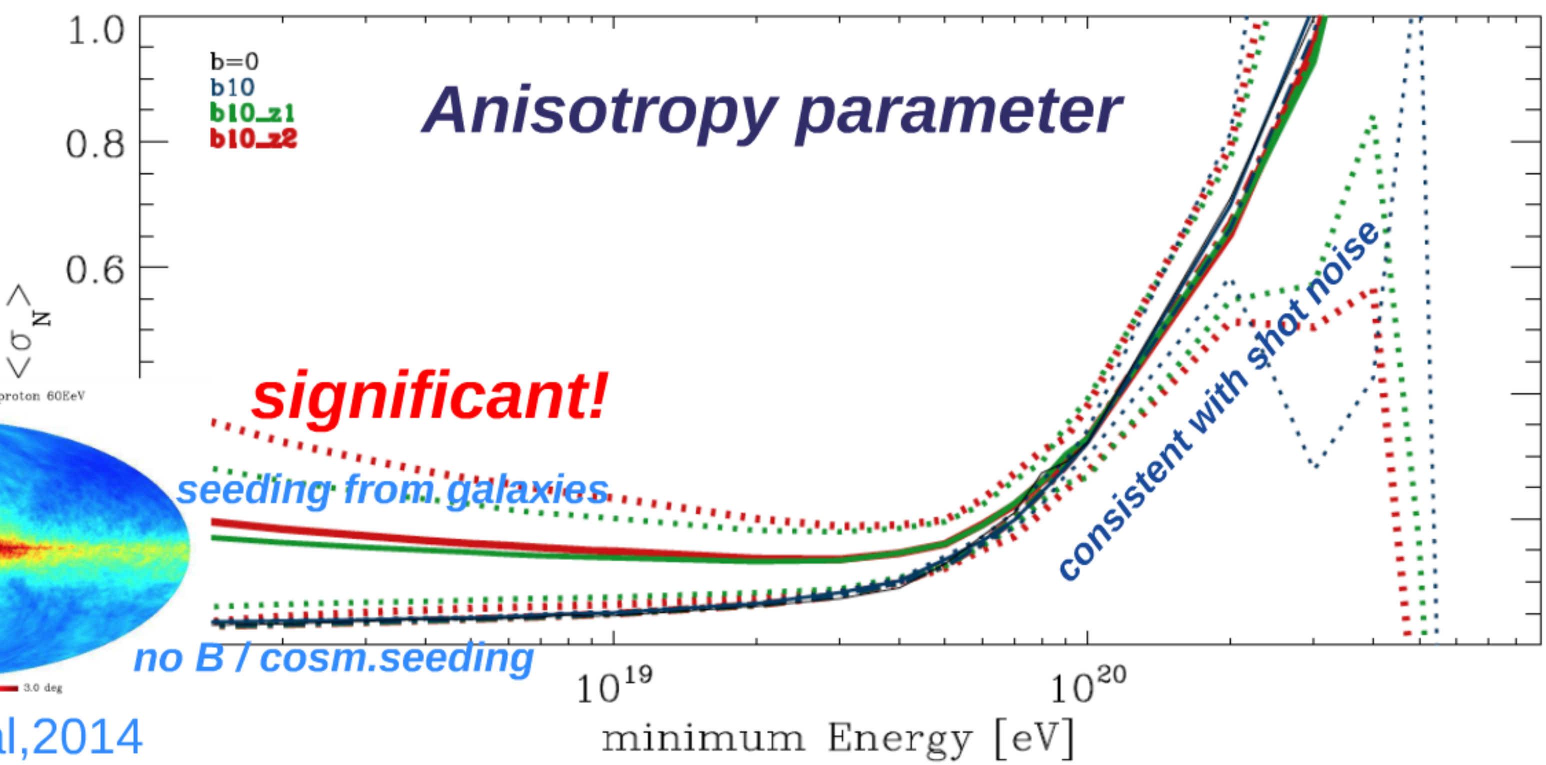
Origin of observed UHECRs

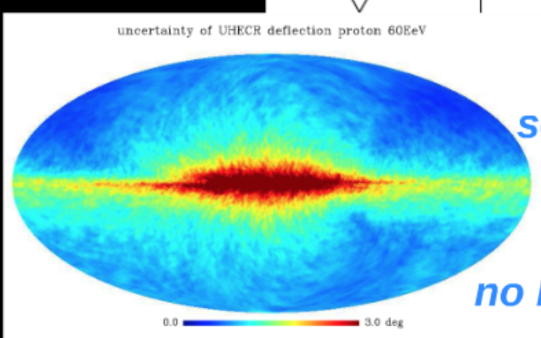


arrival directions







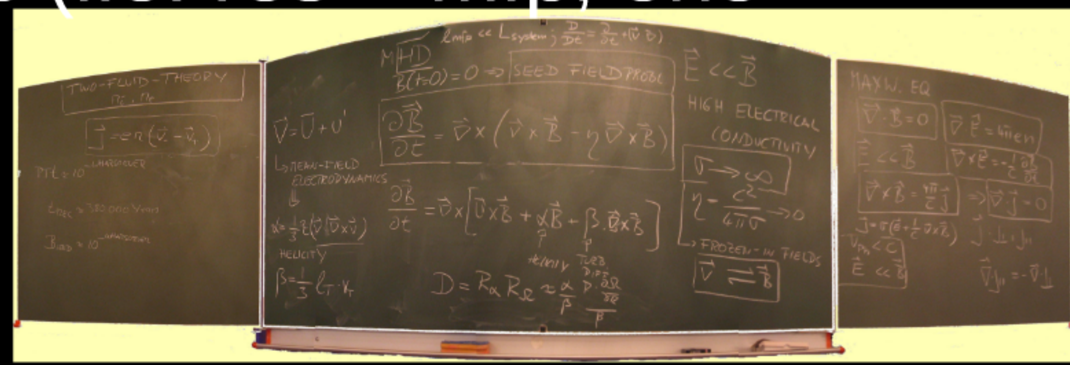


Beck^3+al,2014

Some caveats on what I just said...

About simulations:

- "just" ideal MHD results (i.e. res < mfp, one fluid, no resistivity..)
- needs validation with other MHD schemes



About radio emission from filaments:

- DSA at low density, DSA efficiency for M>>10
- assumed removal of all foregrounds

About UHECRs:

- sources unknown!
- deflection from Milky Way not considered

Final remarks:

- the WHIM not a good place for dynamo amplification (unlike the ICM), due to predominant compressive turbulence

- therefore, any detection of magnetic fields there will teach us crucial information about the seed fields

- the SKA-LOW might detect the radio cosmic web for z<0.2 if DSA is at work and B~10-100 nG

- information on the seed field might also be present in the anisotropy of UHECRs (<10^19 eV)

Thanks