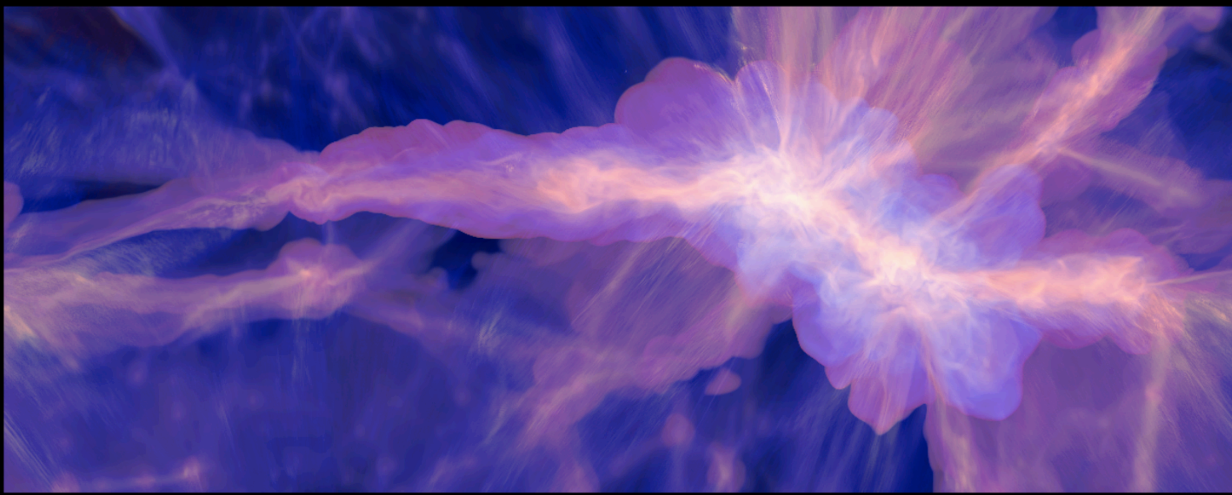
The complex life in cluster outskirts: a (theoretical) low frequency view

The Broad Impact of Low Frequency Observing



Franco Vazza (IRA-Bologna, Universität Hamburg)

M. Brüggen, C. Gheller, G. Brunetti
D. Wittor, A. Bonafede, S. Ettori

AstroFIt 2 Astronomy Fellowships in Italy

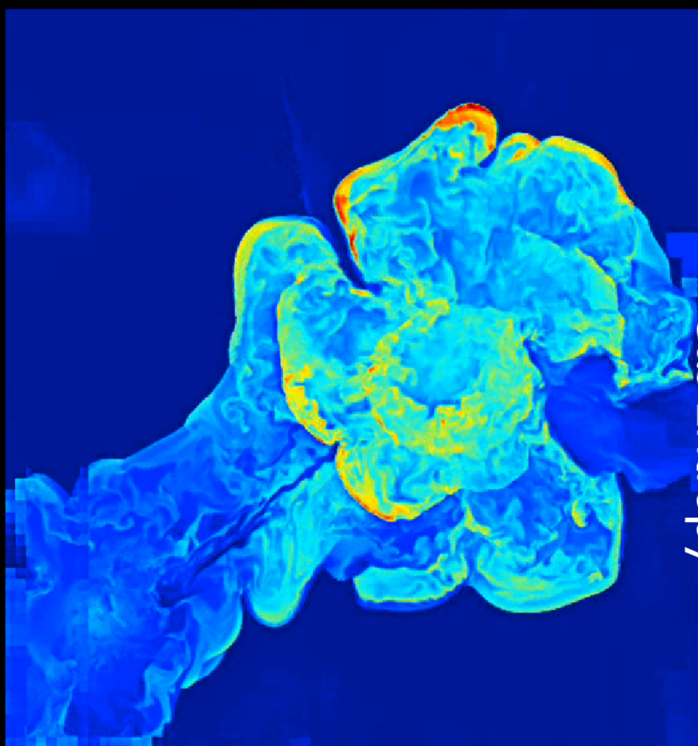
Why are cluster outskirts *complex?*

Still accreting matter today

Irreversible conversion of infall kinetic energy

Out-of-equilibrium conditions

Acceleration of particles, injection of vorticity...



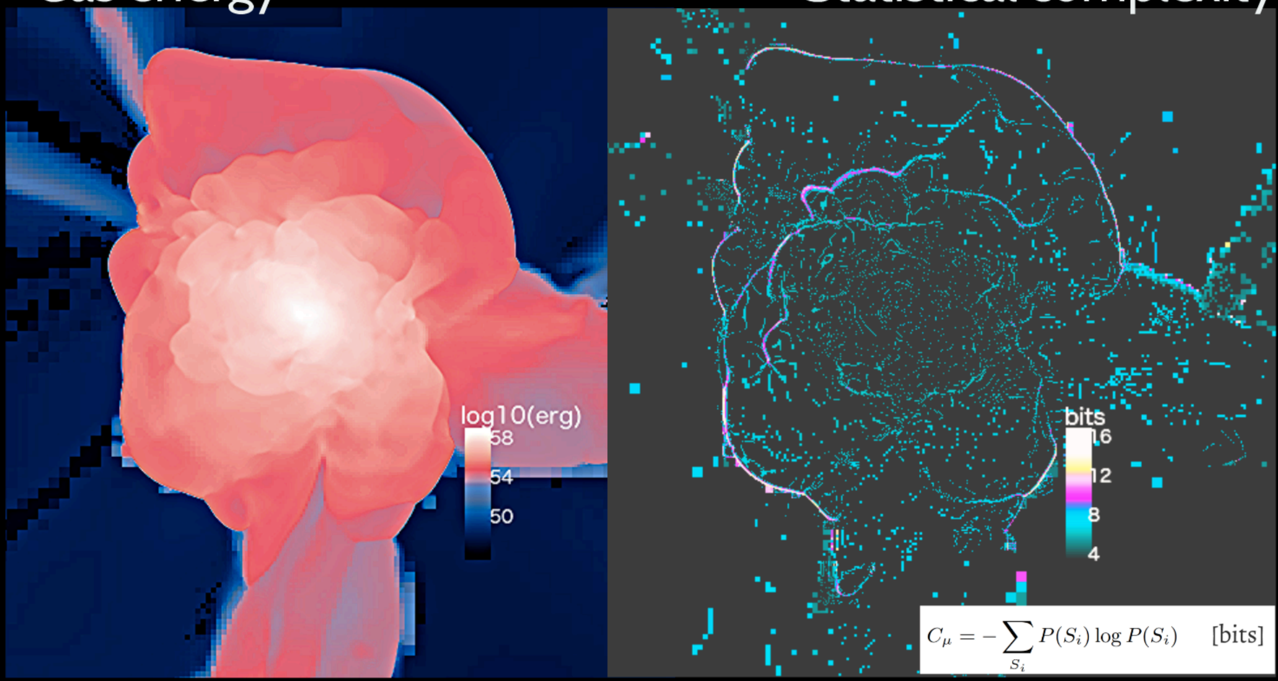
FV, Brunetti, Gheller & Brunino 2010

(see Ryu+03,08, Nagai+07, FV+09, Reiprich+16)

Cluster outskirts are *objectively complex.*

Gas energy

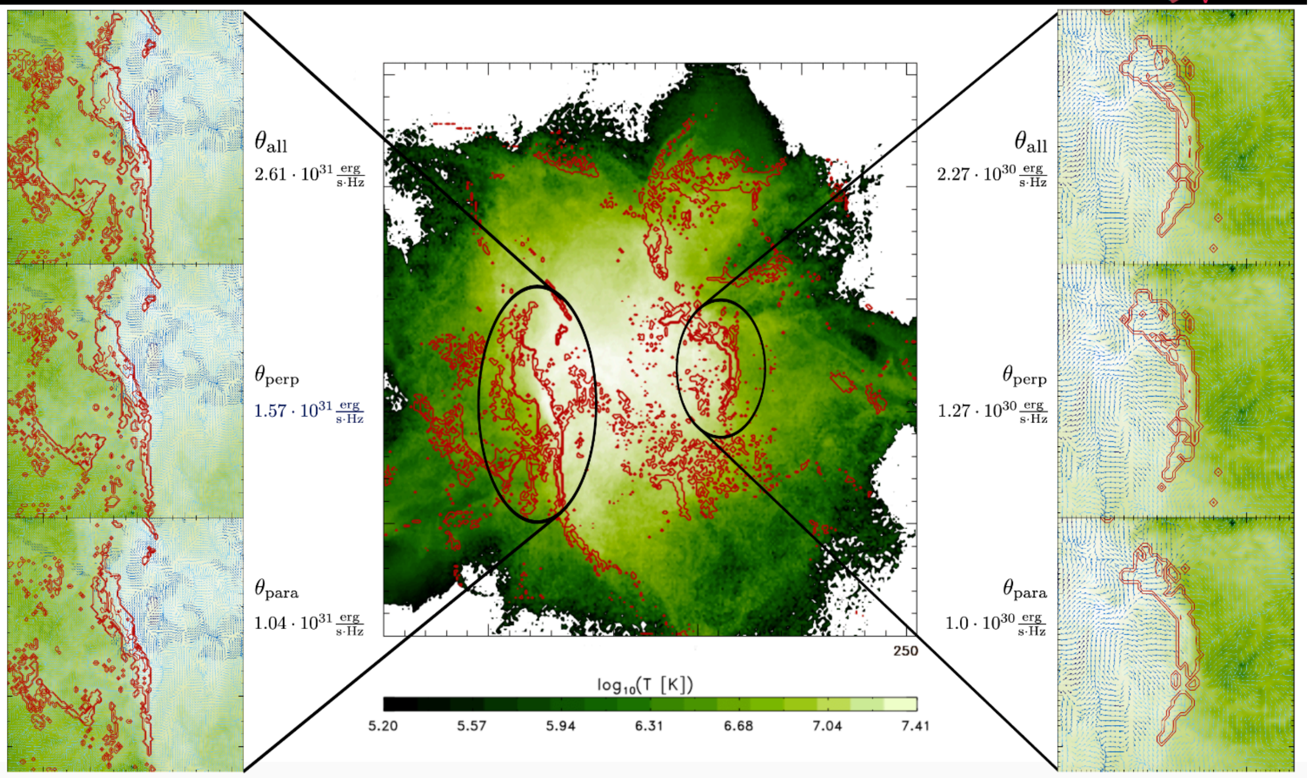
Statistical complexity



"On the complexity and the information content of cosmic structures"
Vazza 2017 MNRAS

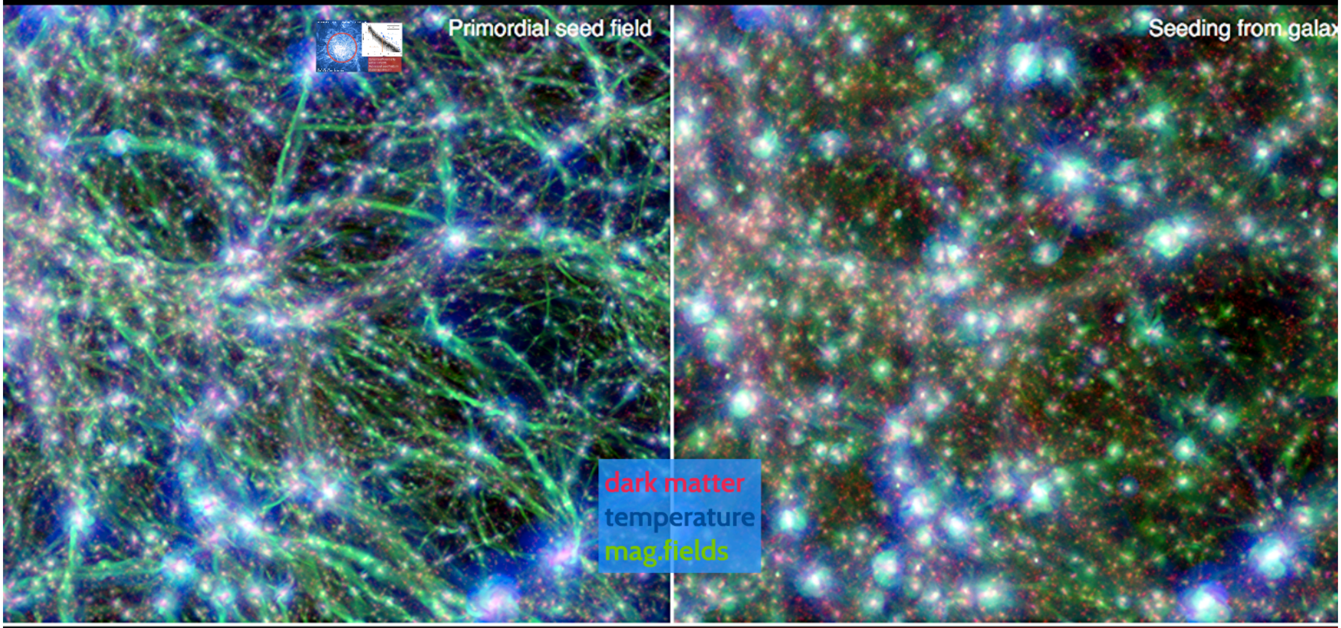
Peripheral radio emission illuminates shock physics.

Properties of radio relic emission may depend on shock *obliquity*



(see Skillman+13, Guo+15,Donnert+16,Kang+17, Nuza+17) ***Wittor, FV, Bruggen 2017 MNRAS***

What is the origin of extragalactic magnetic fields?



ENZO-MHD , 2400^3 cells and DM particles
32 million hours on on Piz-Daint (CSCS)
Part of incoming ERC project *MAGCOW*

(see Donnert+08, FV+14, Cho14,Marinacci+15)

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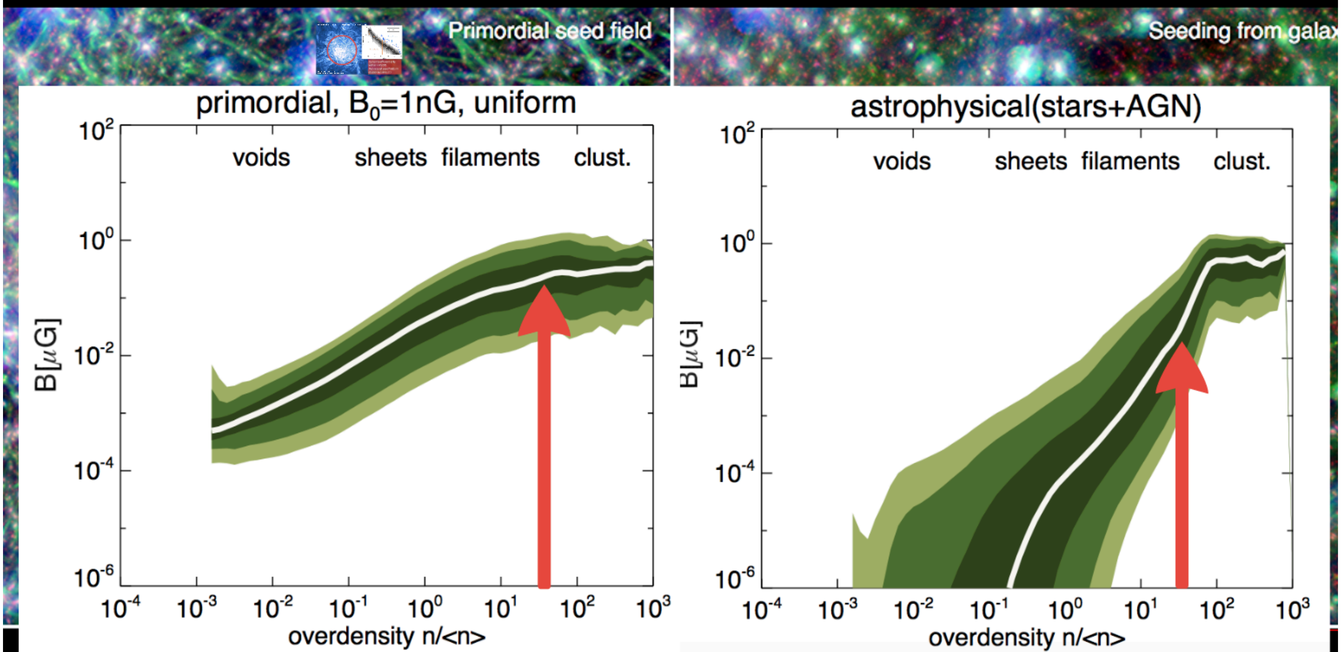

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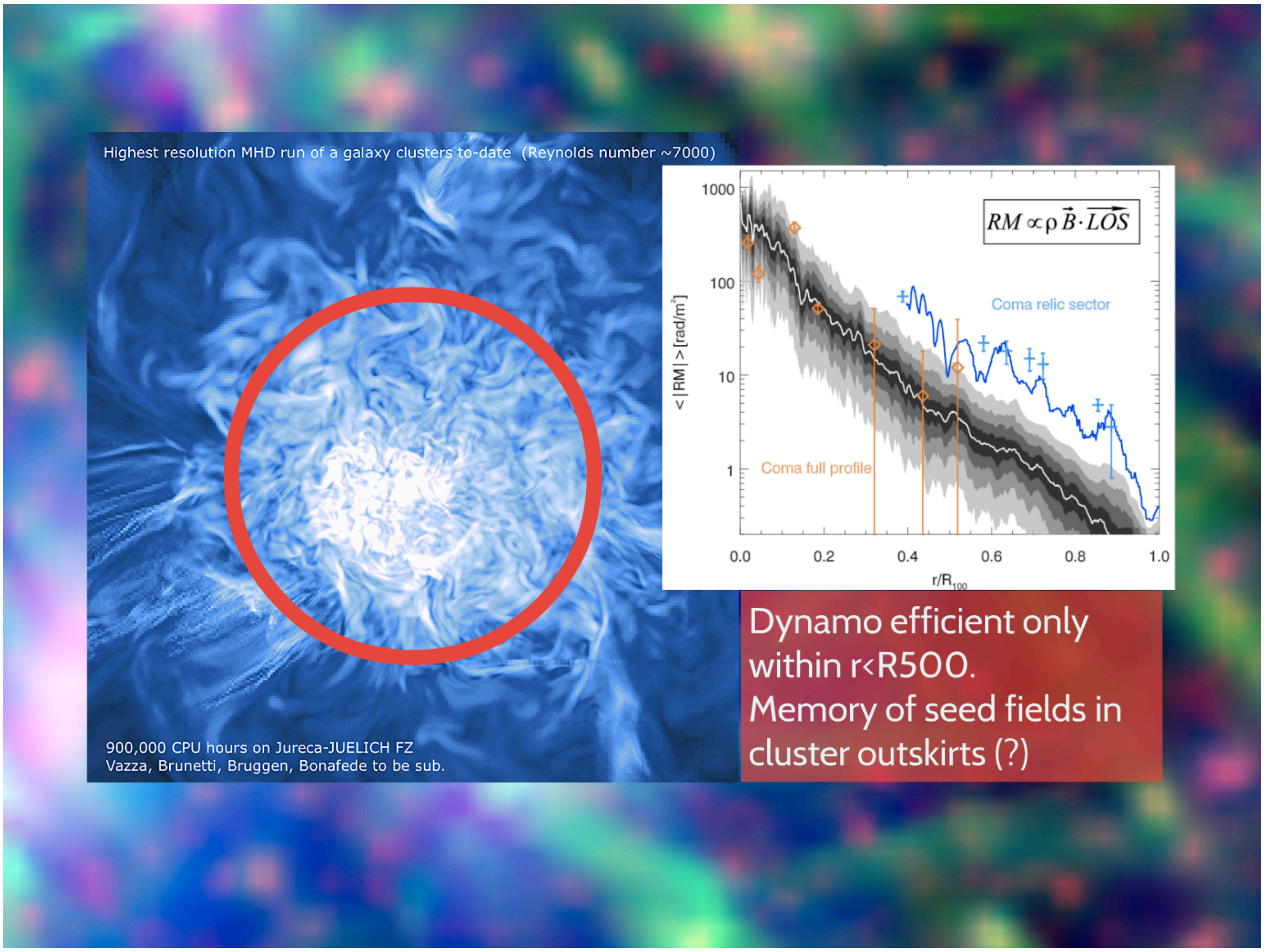


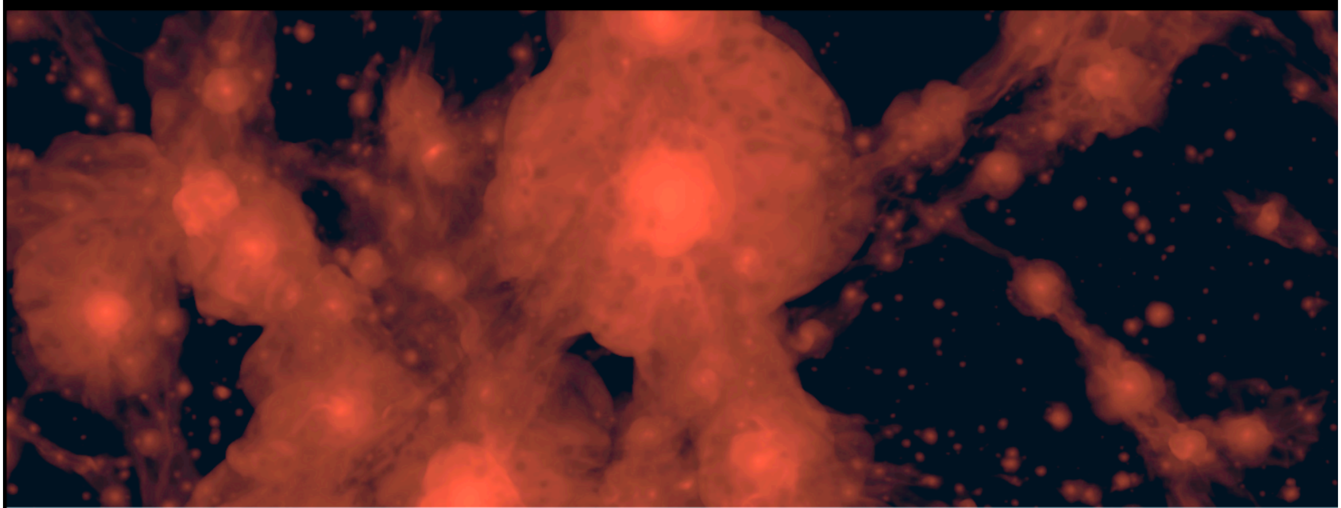
Simulated radio emission from the cosmic web

We assume synch. emission from from electrons accelerated by DSA:

$$P(\nu) \propto \xi_e(M)\, \rho\, V_s^3\, B^2\, A_s$$

(Hoeft & Brüggen 07)

Maximum accel.efficiency ~0.07%
Magnetic fields ~μG (clusters) to ~nG-100nG (filaments)



FV,Ferrari,Bruggen+15 a,b FV 2016

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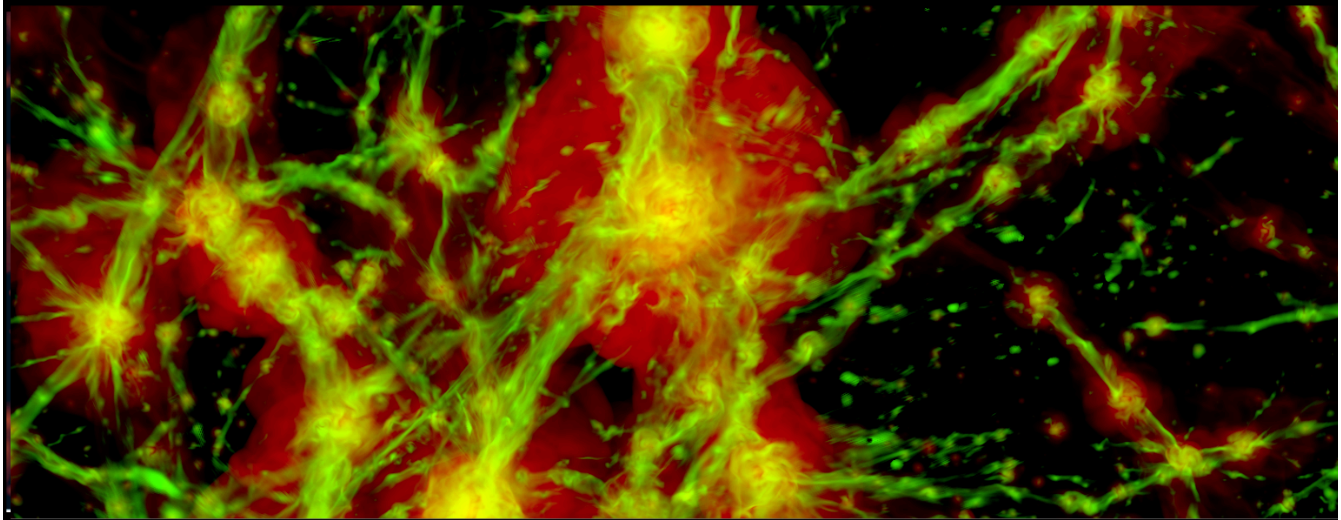

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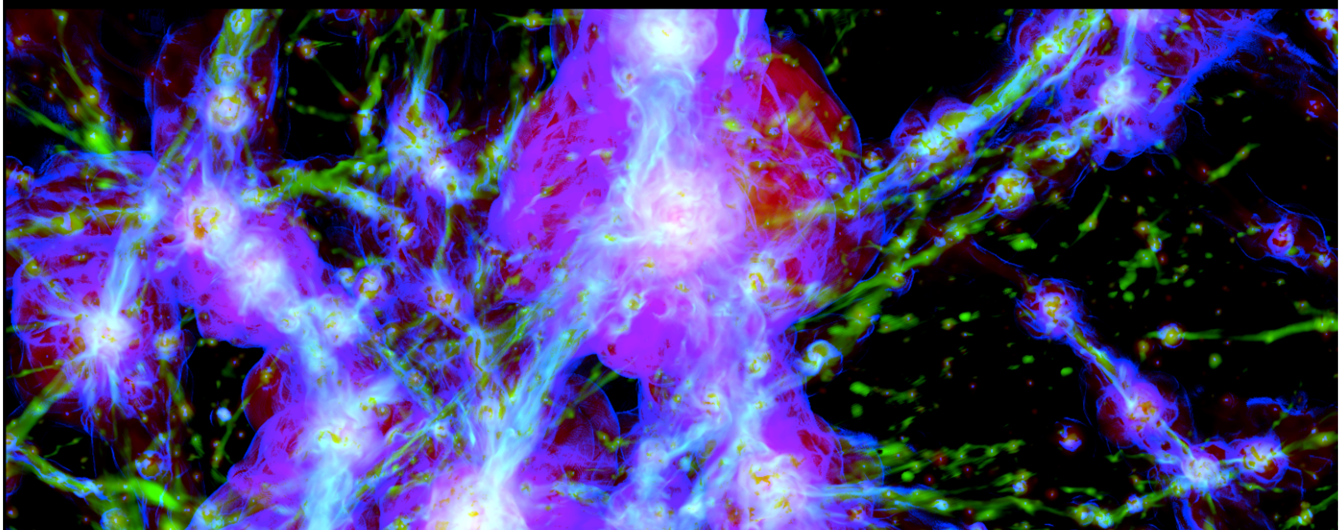

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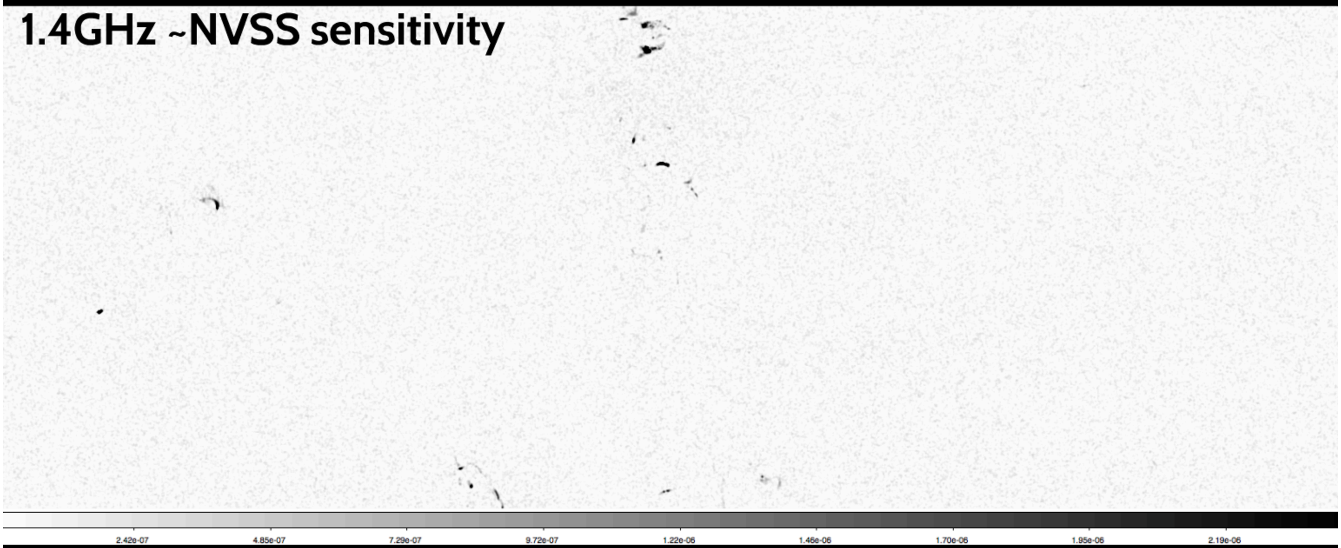

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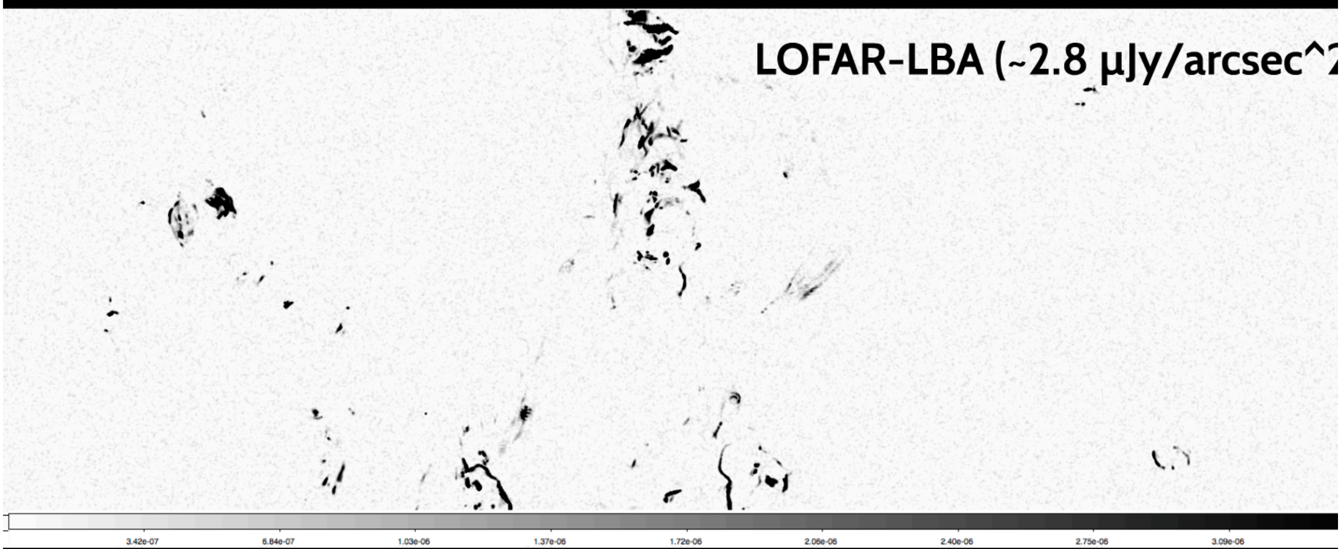

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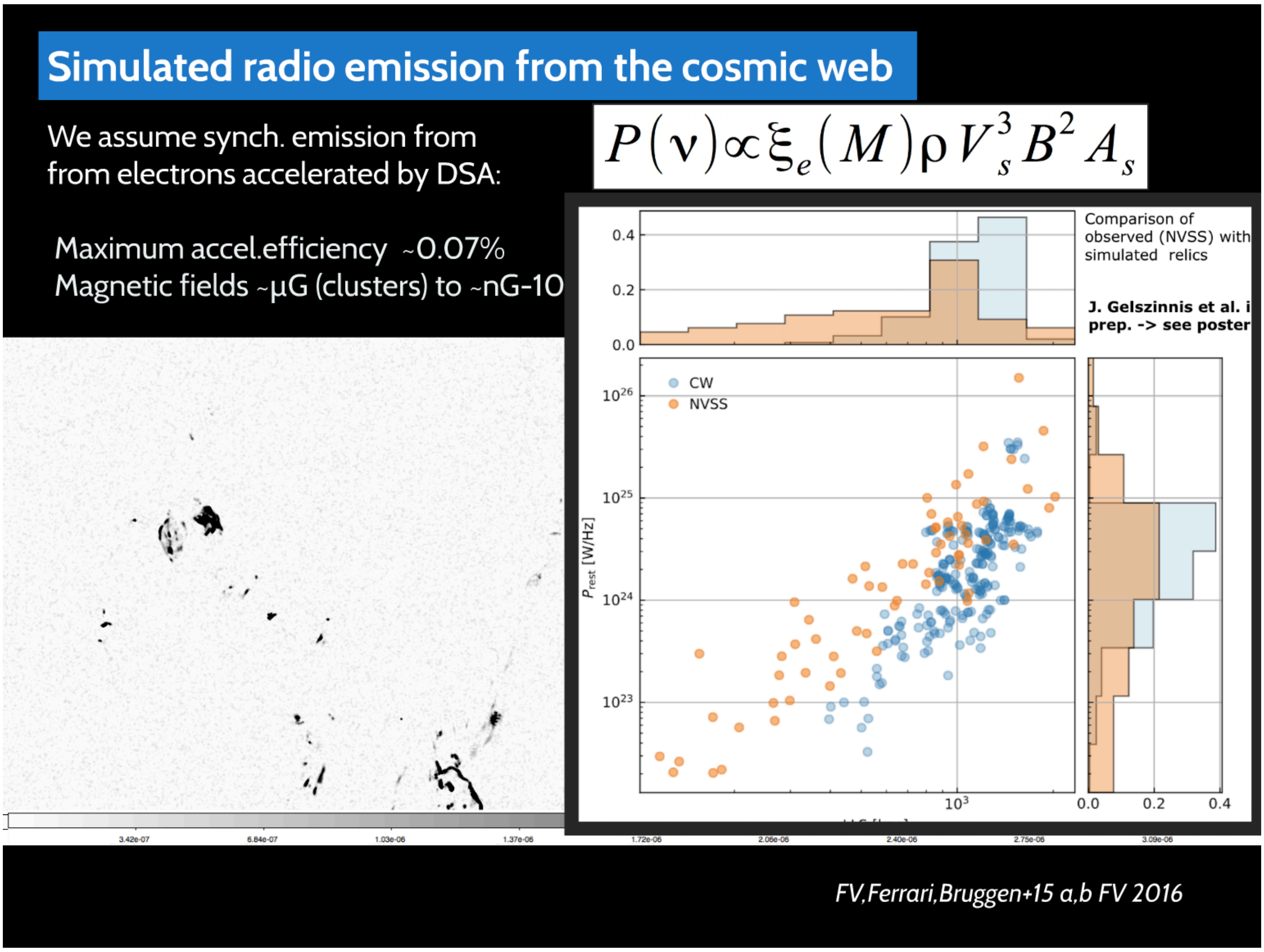
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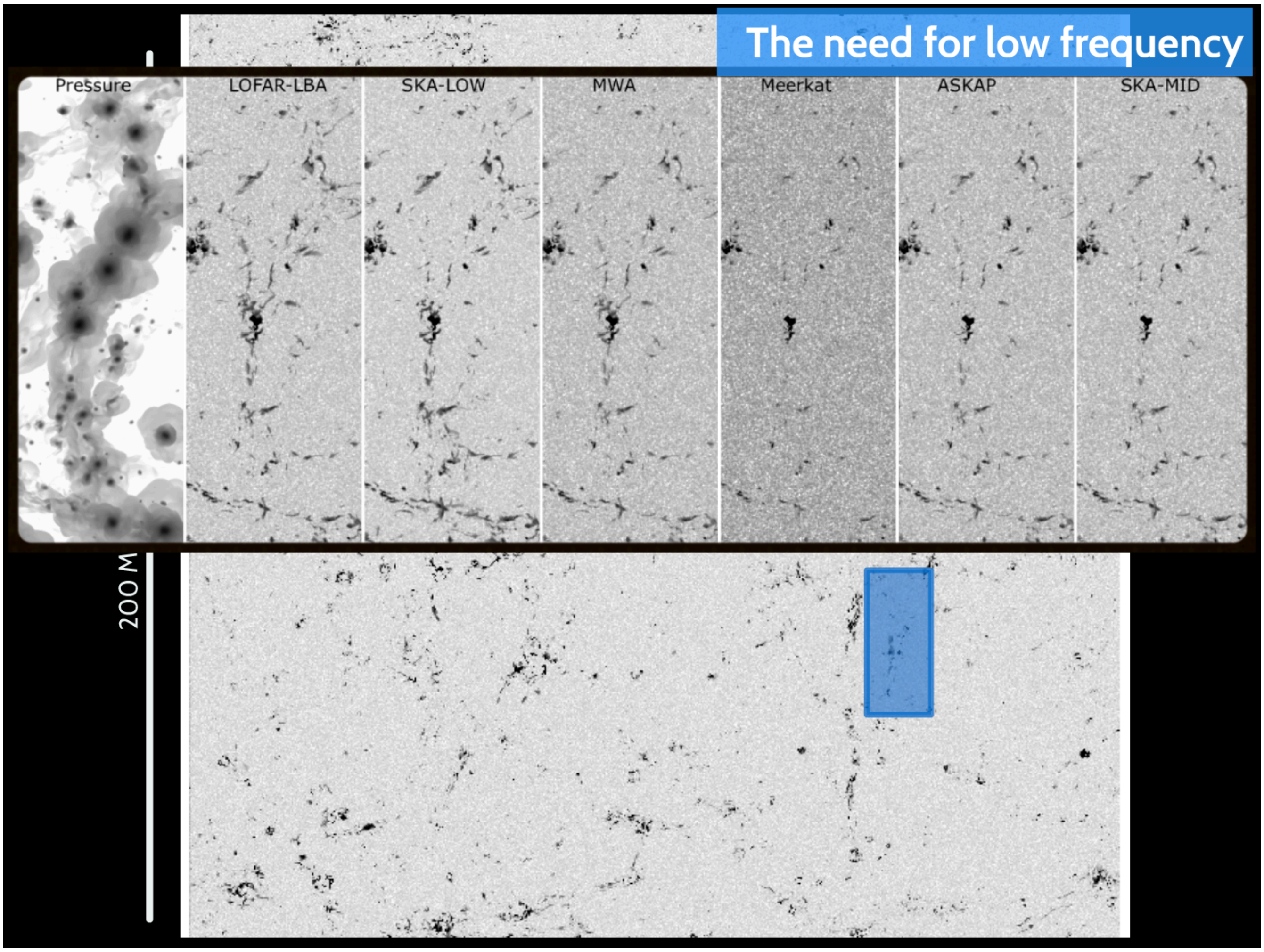
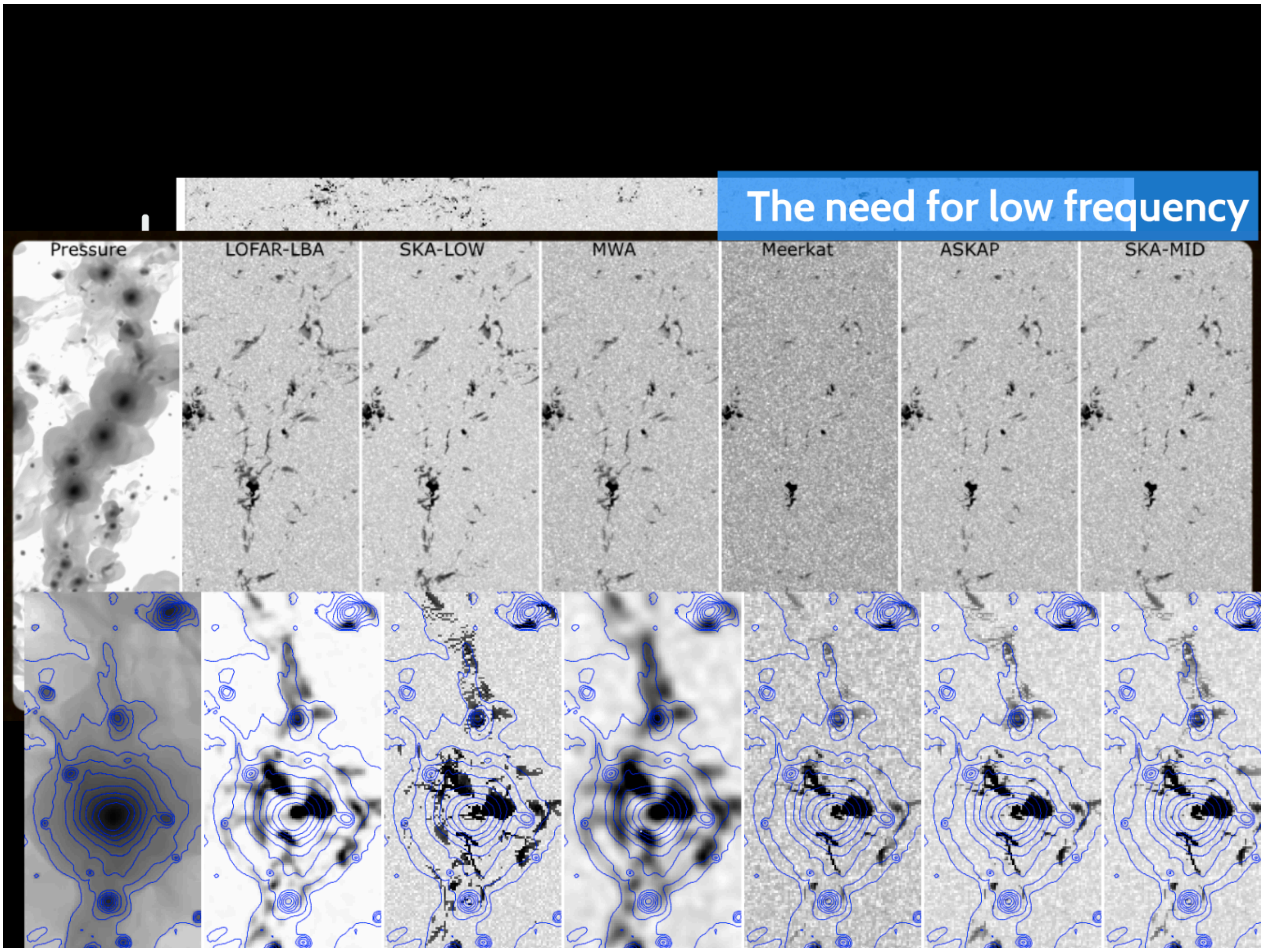
Magnetic fields ~μG (clusters) to ~nG-10
Comparison of observed (NVSS) with simulated relics
J. Gelszinnis et al. i prep. -> see poster
CW
NVSS
P_{rest} [W/Hz]
10^{26}
10^{25}
10^{24}
10^{23}
10^3
0.0
0.2
0.4
3.42e-07
6.84e-07
1.03e-06
1.37e-06
1.72e-06
2.06e-06
2.40e-06
2.75e-06
3.09e-06
FV,Ferrari,Bruggen+15 a,b FV 2016


The need for low frequency
Pressure
LOFAR-LBA
SKA-LOW
MWA
Meerkat
ASKAP
SKA-MID
200 M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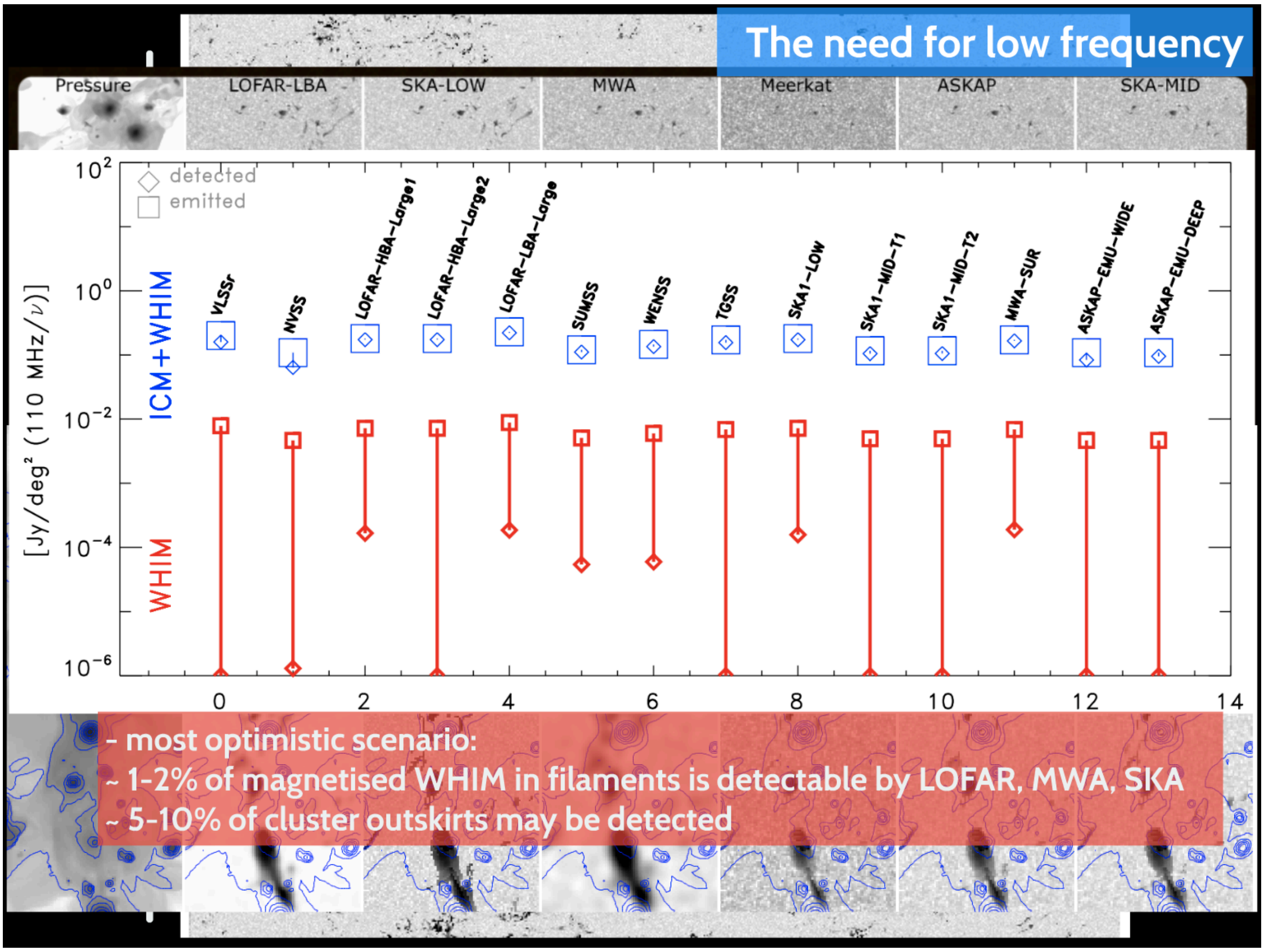
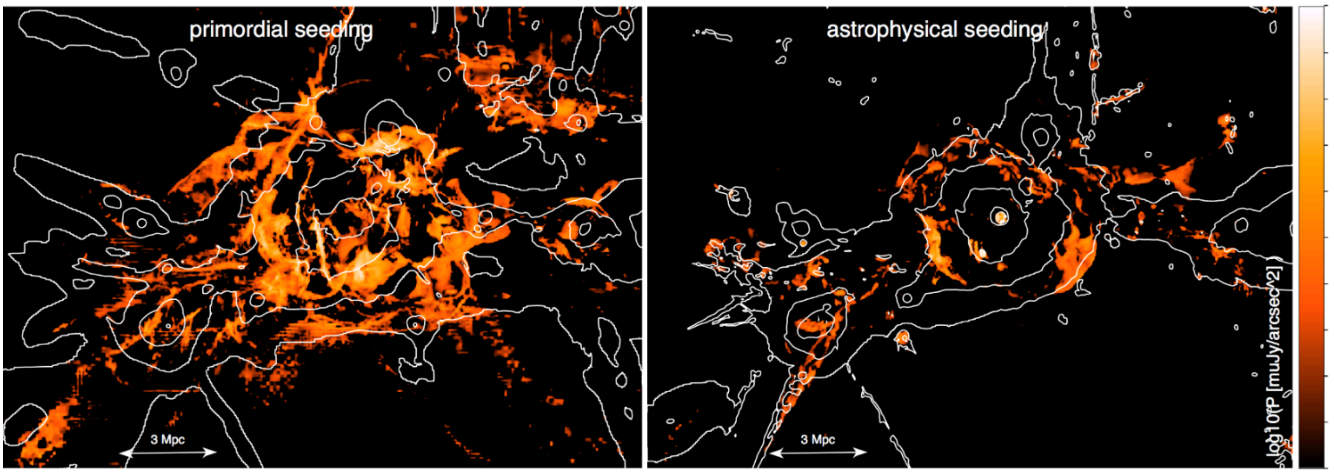

The need for low frequency
Pressure
LOFAR-LBA
SKA-LOW
MWA
Meerkat
ASKAP
SKA-MID
detected
emitted
[Jy/deg² (110 MHz/ν)]
ICM+WHIM
WHIM
VLSSr
NVSS
LOFAR-HBA-Large1
LOFAR-HBA-Large2
LOFAR-LBA-Large
SUMSS
WENSS
TGSS
SKA1-LOW
SKA1-MID-T1
SKA1-MID-T2
MWA-SUR
ASKAP-EMU-WIDE
ASKAP-EMU-DEEP
- most optimistic scenario:
- 1-2% of magnetised WHIM in filaments is detectable by LOFAR, MWA, SKA
- 5-10% of cluster outskirts may be detected

Emission from cluster outskirts & magnetogenesis

Emission in "primordial" model (B0=0.1nG)
~10-100 higher at R200 than in "astrophysical" seeding model



Signatures ~detectable only by stacking at low frequency
(else: cross-correlation function Vernstrom+17,Brown+17)

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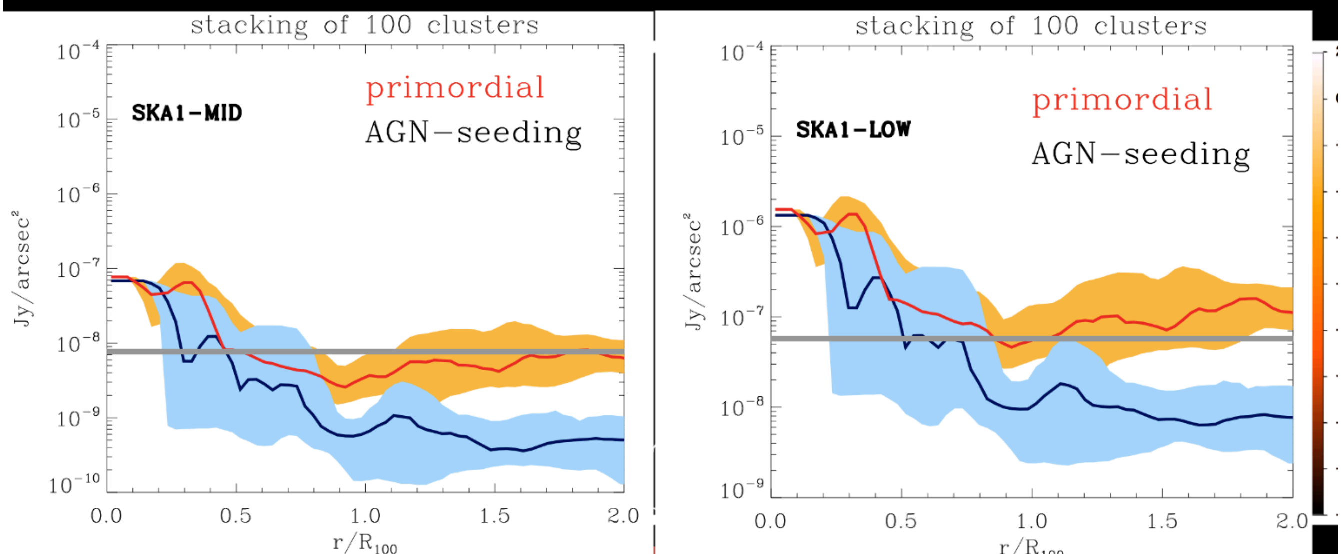

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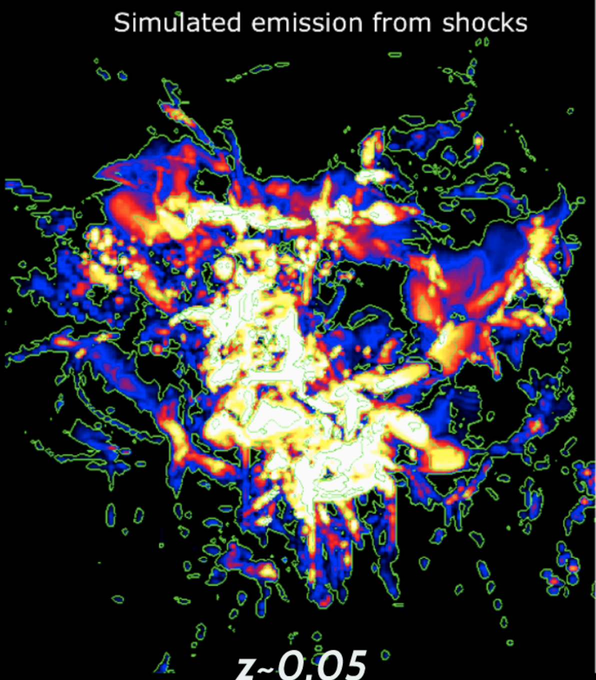
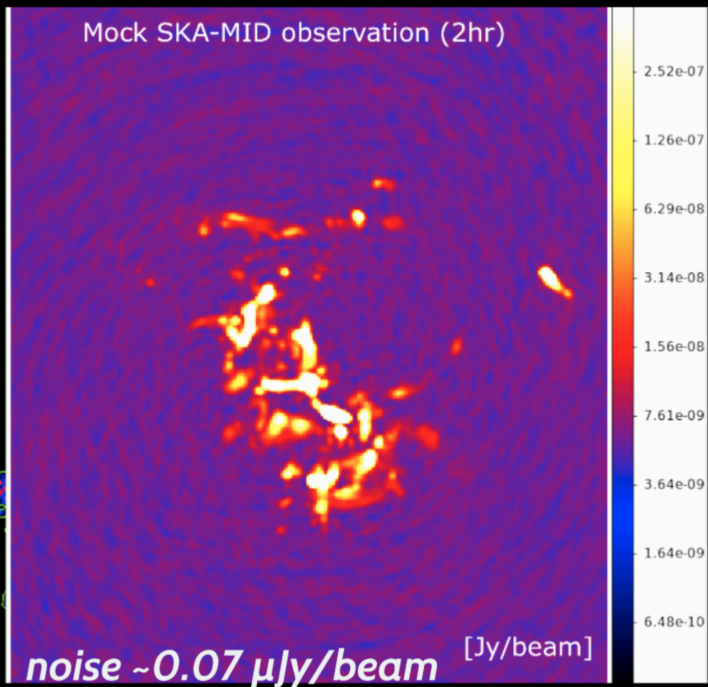
Work in progress (1): simulated SKA-MID observation with STIMELA

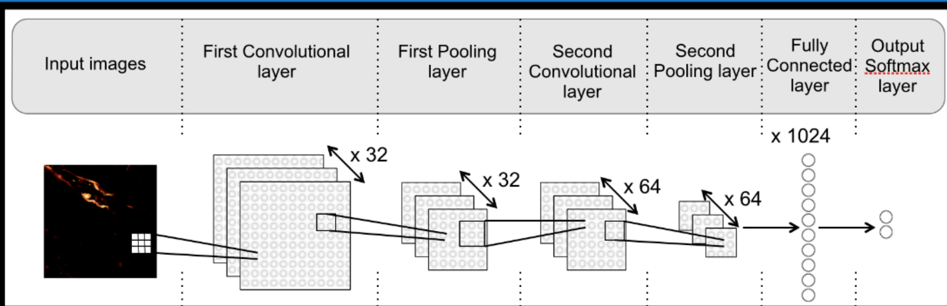
thank to S.Makhathini, I.Prandoni & F.Tinarelli





Weak diffuse emission from accretion shock/filaments undetectable
Plenty of complex radio substructures detectable within R200

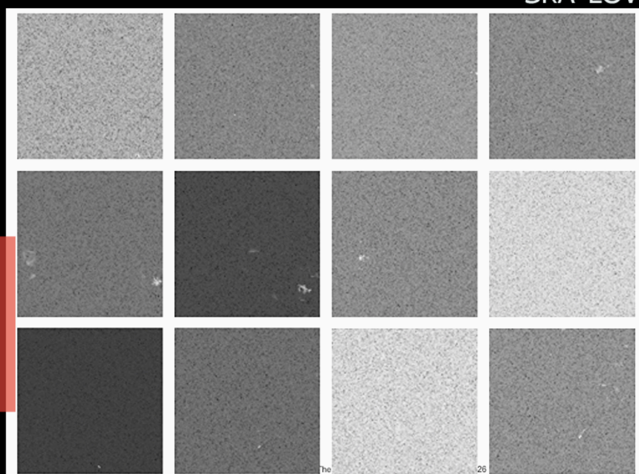
Work in progress (2): detecting of diffuse emission with Convolutional Neural Network



Training: 3,000,000 2x2 deg imag.
1/3 pure noise
1/3 only pointlike sources
1/3 only diffuse emission

Results (preliminary):
~90% accuracy for noise=0.2μJy/arcsec^2
~83% accuracy for noise=1.0μJy/arcsec^2
0.3 ms to classify each image (on GPU)

SKA-LOW



Courtesy of C. Gheller @CSCS(ETHZ)

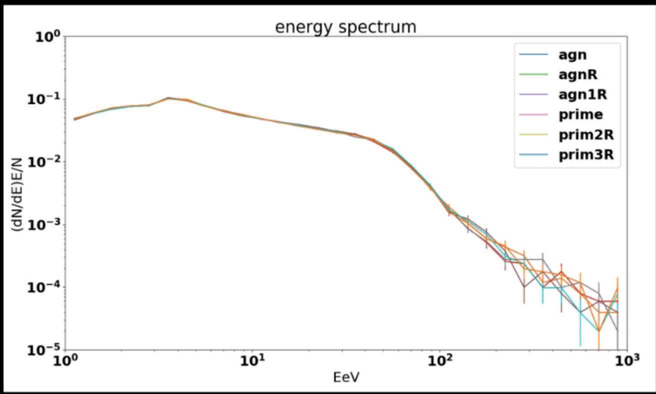
...more realistic noise models and mock observations are needed

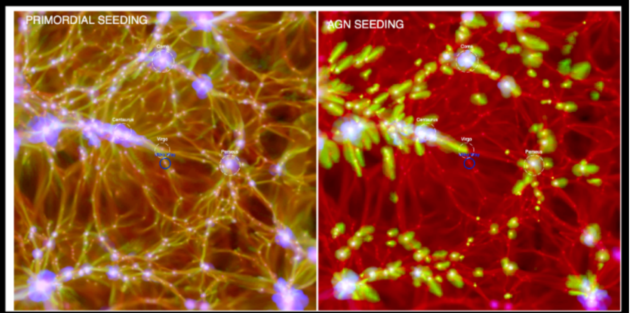
What is the best observable of magnetogenesis?

- **Ultra-high energy cosmic rays?**

No. Very different models give equal results for >1EeV

Hackstein,FV+2017 MNRAS





- **Fast radio burst?** *Hinz,FV et al. in prep.*
- **Axionlike particle oscillations?** *Montanino,FV et al. PRL*
- **Inverse compton cascade?** *Hackstein et al. in prep.*

Probably not: sources unknown, complex physics, signal polluted by too many structures, Milky Way foreground...

The radio window will likely remain the best.

Summary:

- Interesting out of equilibrium conditions in cluster outskirts

- They will give crucial clues on magnetogenesis (and acceleration physics)

- Low frequency gives the best chances of detection

Thanks

Courtesy of T.Jones