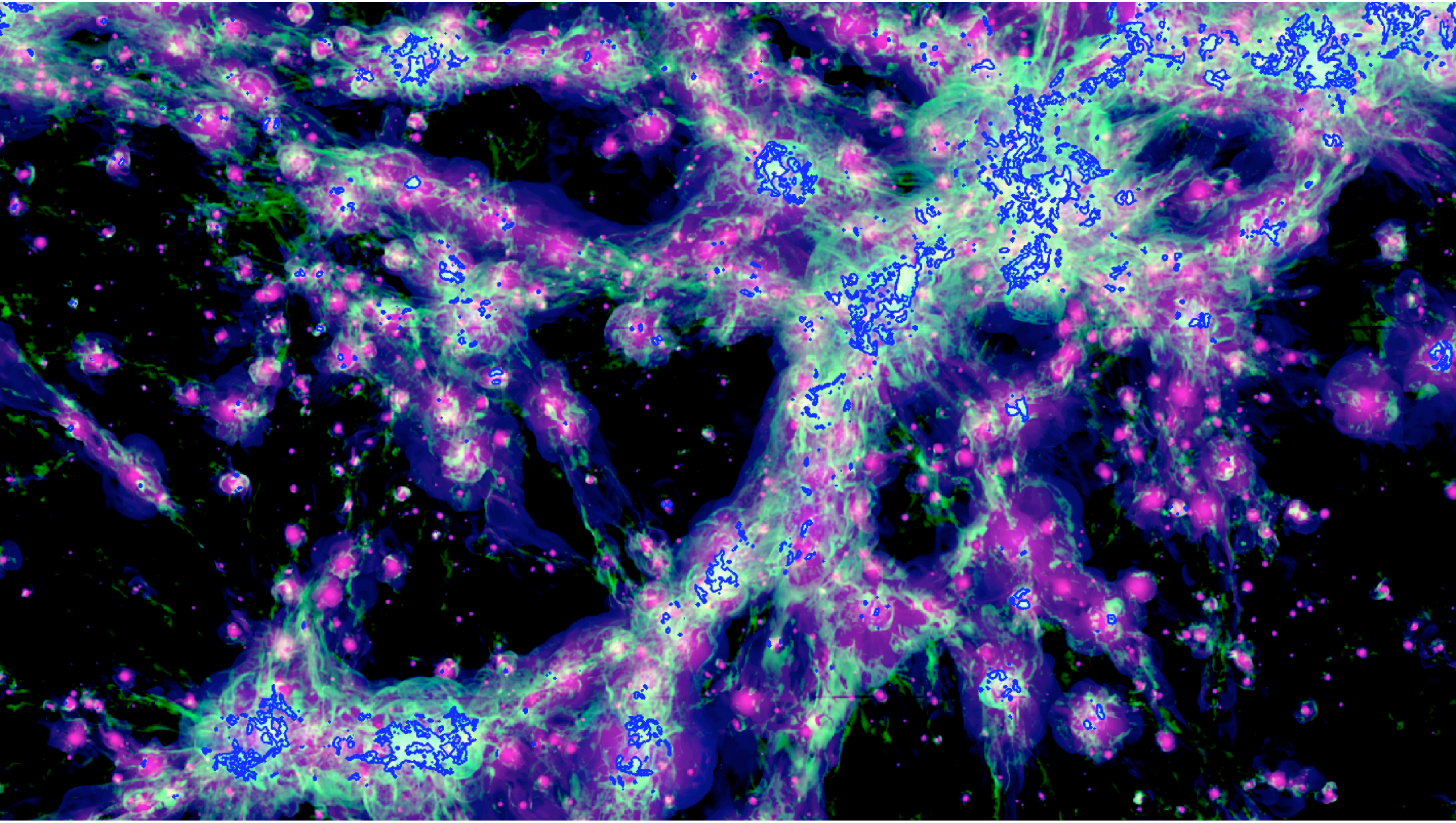
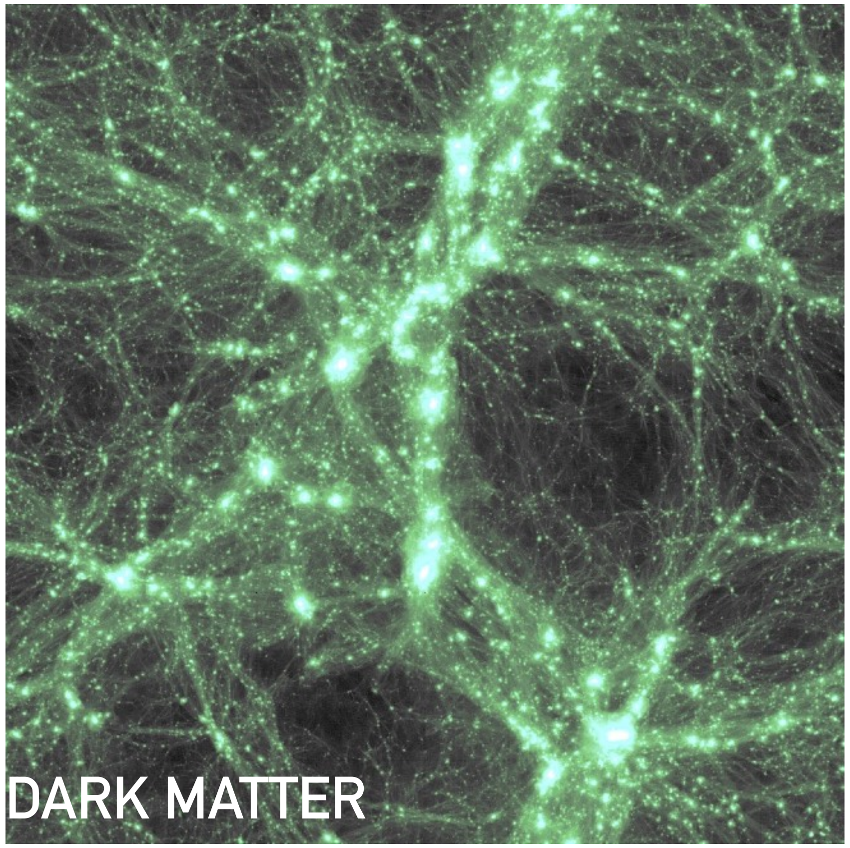
GALAXY CLUSTERS AND THE COSMIC WEB WITH *SKA* & *ATHENA*



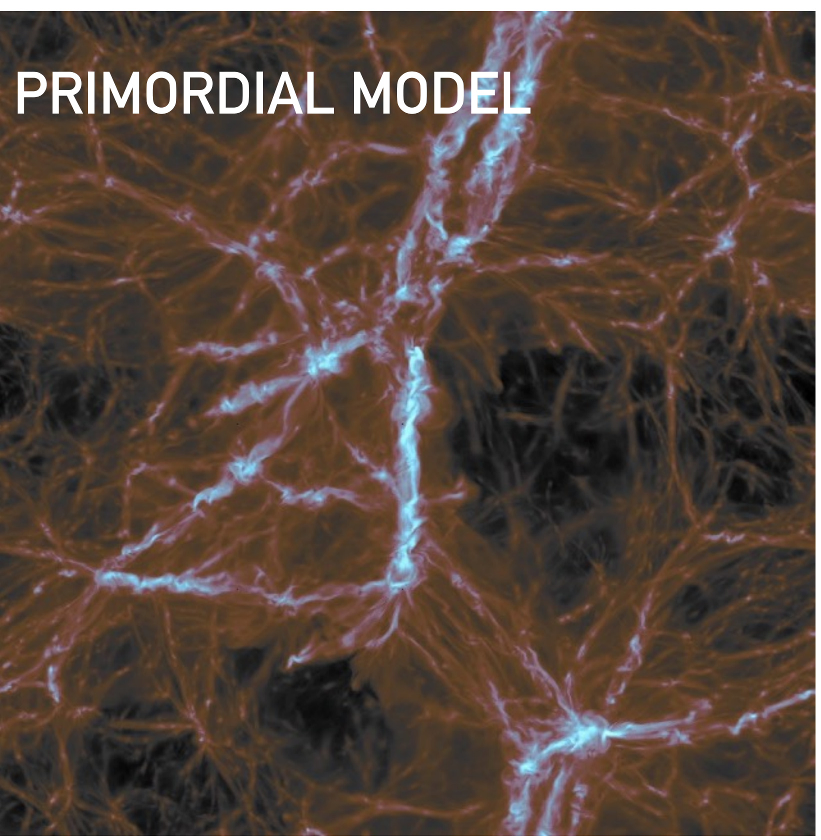
F. Vazza (Università di Bologna, Universität Hamburg, IRA-INAF)

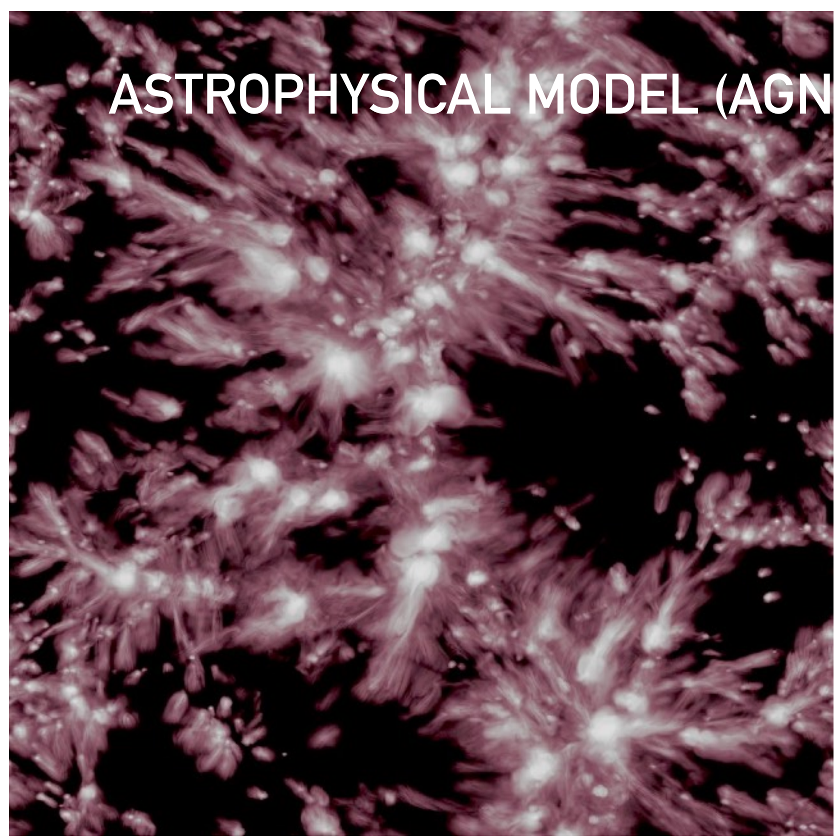
THE COSMIC WEB & MAGNETOGENESIS

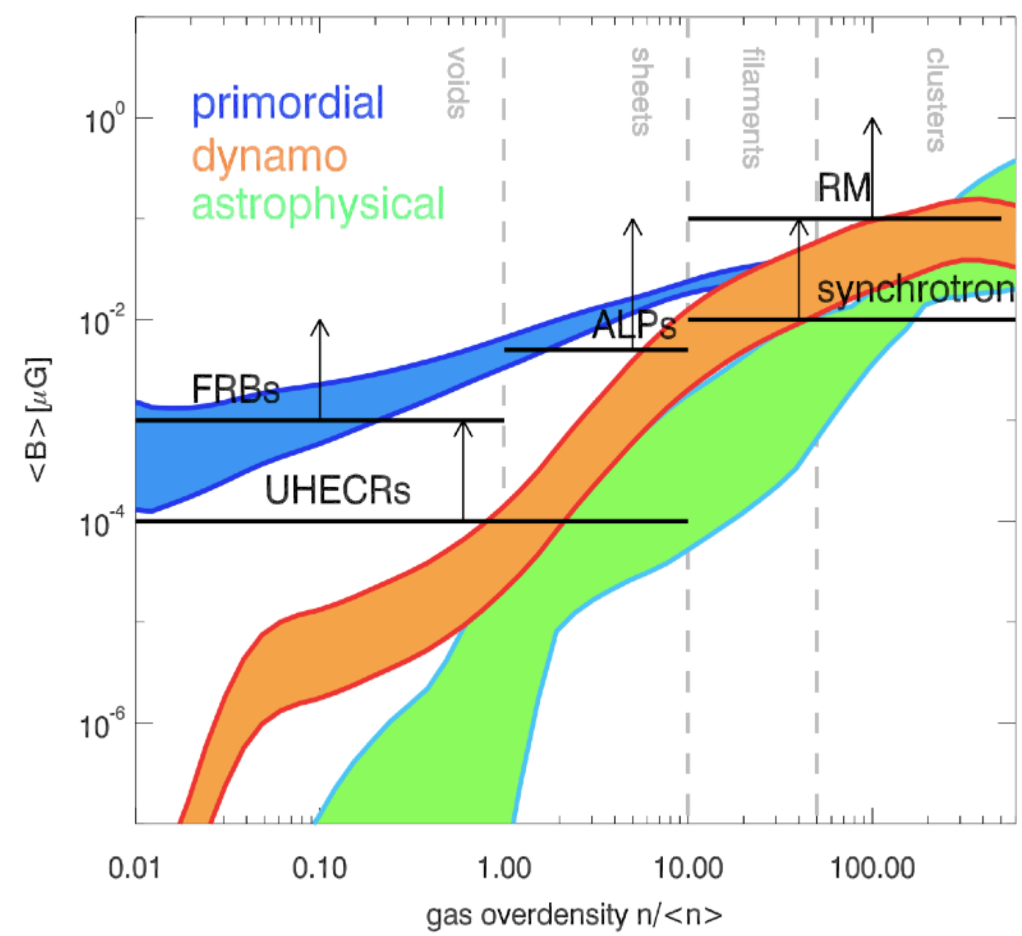
(FV, et al. 2017 CQG)



- **ENZO-MHD** simulations on the grid
- Primordial vs Astrophysical scenarios (25 in total)
- ~μG fields within halos, very different expectations in **filaments and cluster outskirts.**
- many (challenging) observational probes to test
- advanced computer **simulations** to put theories to the test and assist radio **surveys** (+ others)







models archived and shared via via INAF IA2

(see also Donnert+2008, Cho+14,Katz+2018)

THE COSMIC WEB AND COSMIC SHOCKS

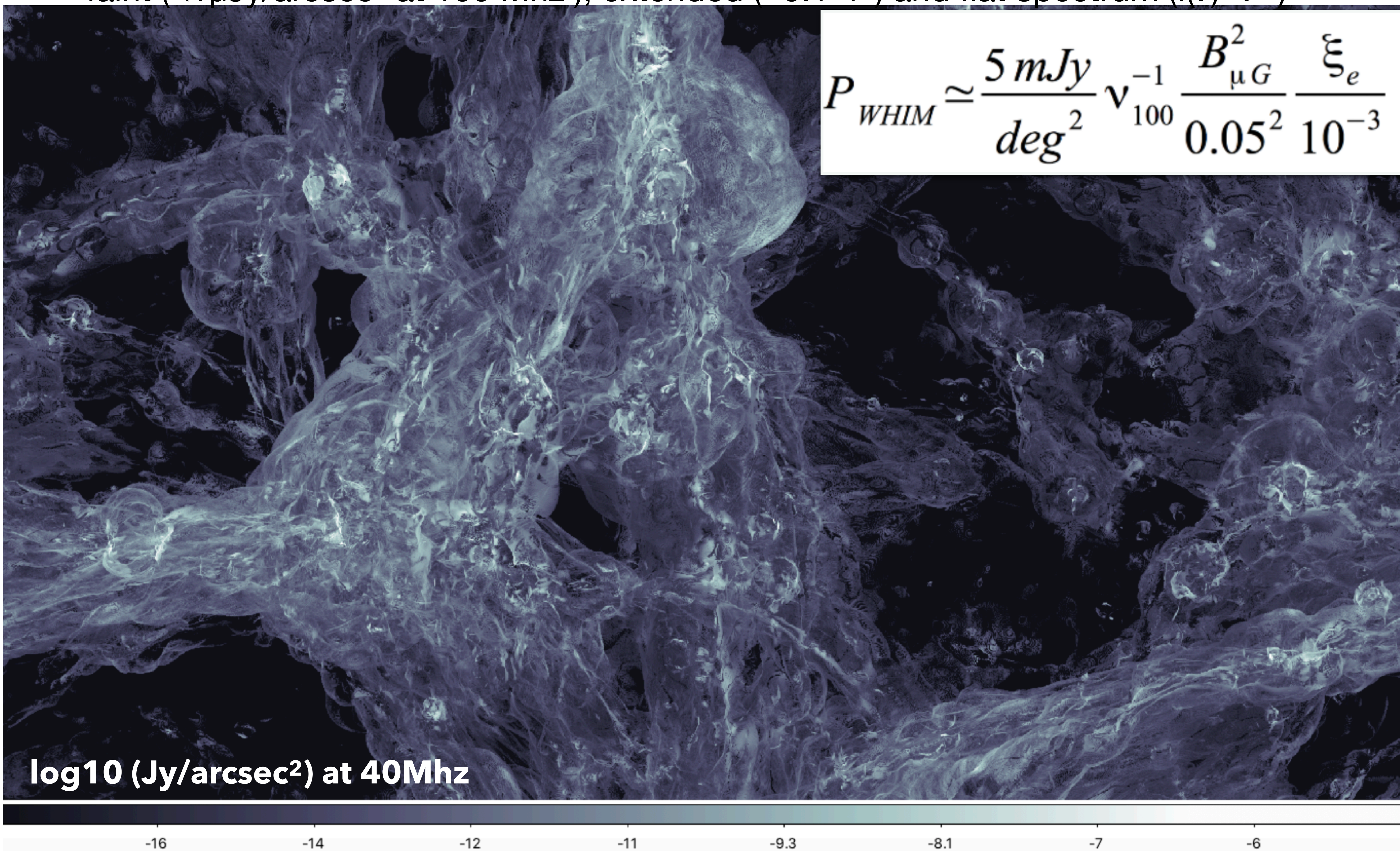
Vazza & Gheller for #Athena Nugget 26

THE COSMIC WEB IN THE RADIO WINDOW

(FV, Ferrari, Bonafede+ 2015 A&A)

Expected emission from the cosmic web:
faint (<1μJy/arcsec² at 100 Mhz), extended (~0.1-1°) and flat spectrum ($I(\nu) \sim \nu^{-1}$)

$$P_{WHIM} \simeq \frac{5\,mJy}{deg^2} \nu_{100}^{-1} \frac{B_{\mu G}^2}{0.05^2} \frac{\xi_e}{10^{-3}}$$



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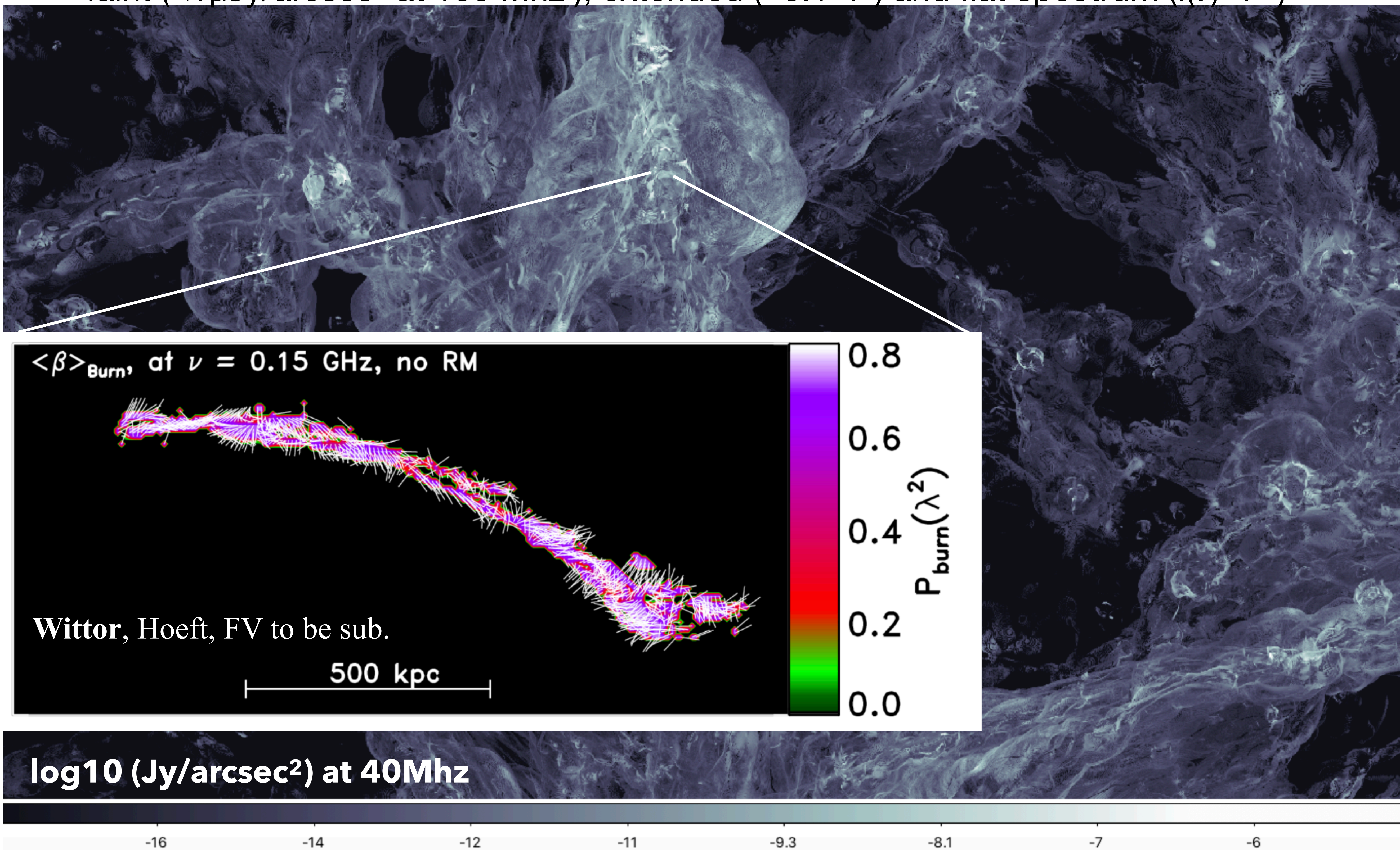

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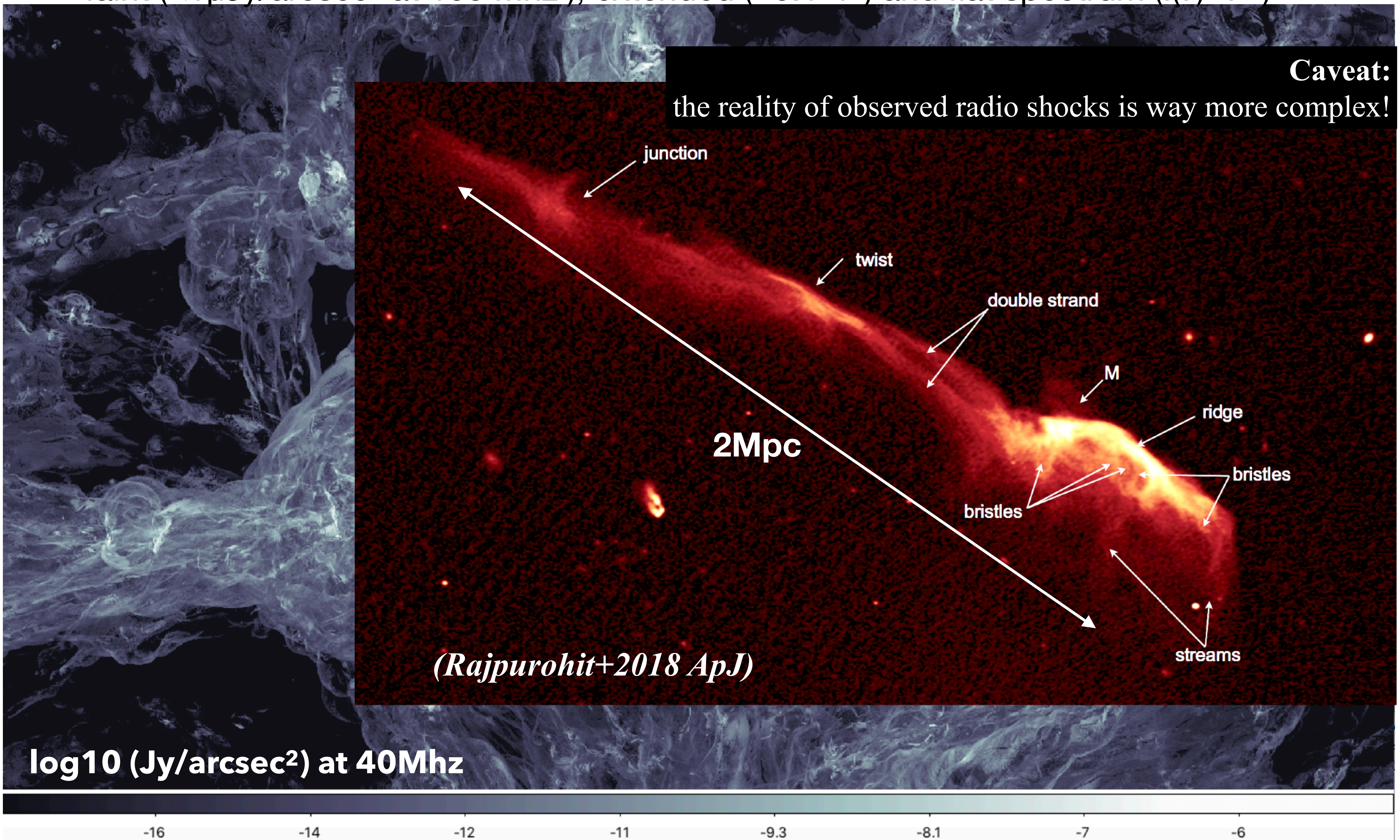
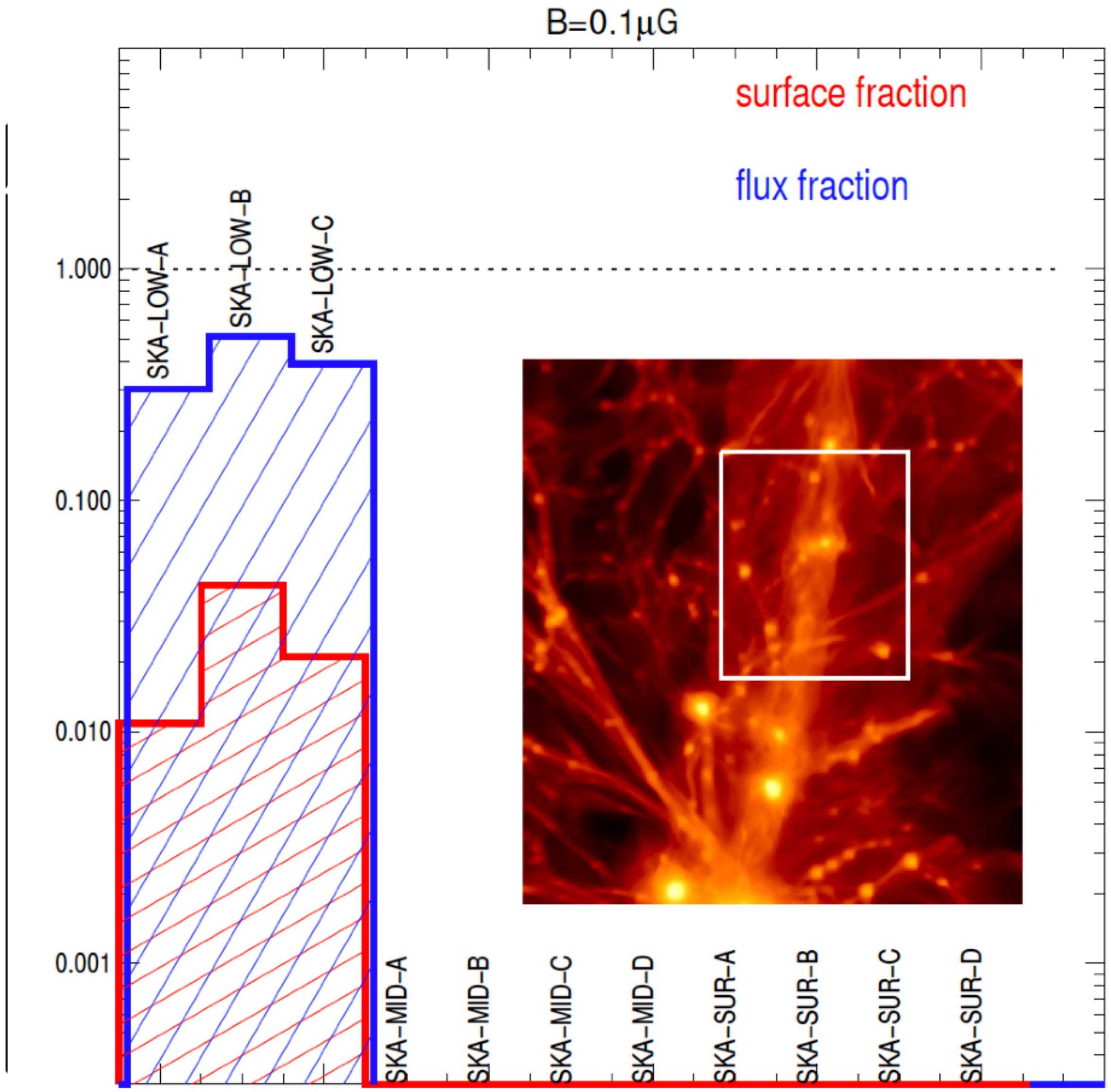
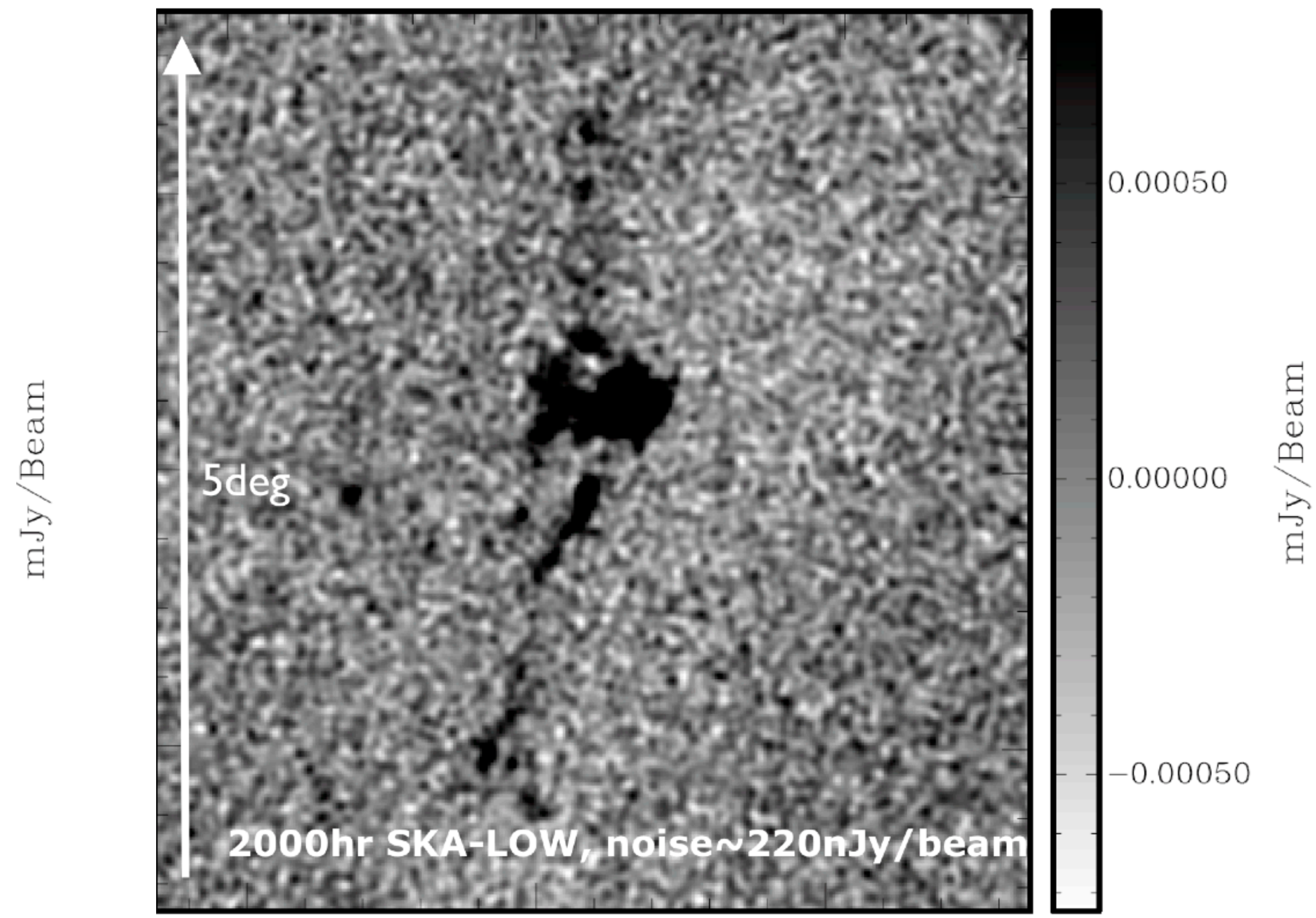


THE RADIO COSMIC WEB: SKA-LOW (& LOW FREQUENCIES)

(FV, Ferrari+ 2015 AASKA)



Mock observations by R. Braun



The tip of the iceberg of filaments may be visible with **SKA1-LOW** surveys (~13μJy/beam)

The spine of the cosmic web may become detectable with ~10^3 s integrations(~0.22μJy/beam)

Confusion noise is the limiting factor, **SKA1-MID** surveys can help removing sources.

(see also Brown 2011)

SKA & ATHENA: SYNERGIES ON THE COSMIC WEB

*(FV, **Ettori, Roncarelli**, Angelinelli, Gheller+ to be sub.)*

ATHENA/XIFU (“core”)

0.8 - 1.2 keV assuming <u>1 Megasecond</u>

FOV=5’x5’ A=9947 cm^2

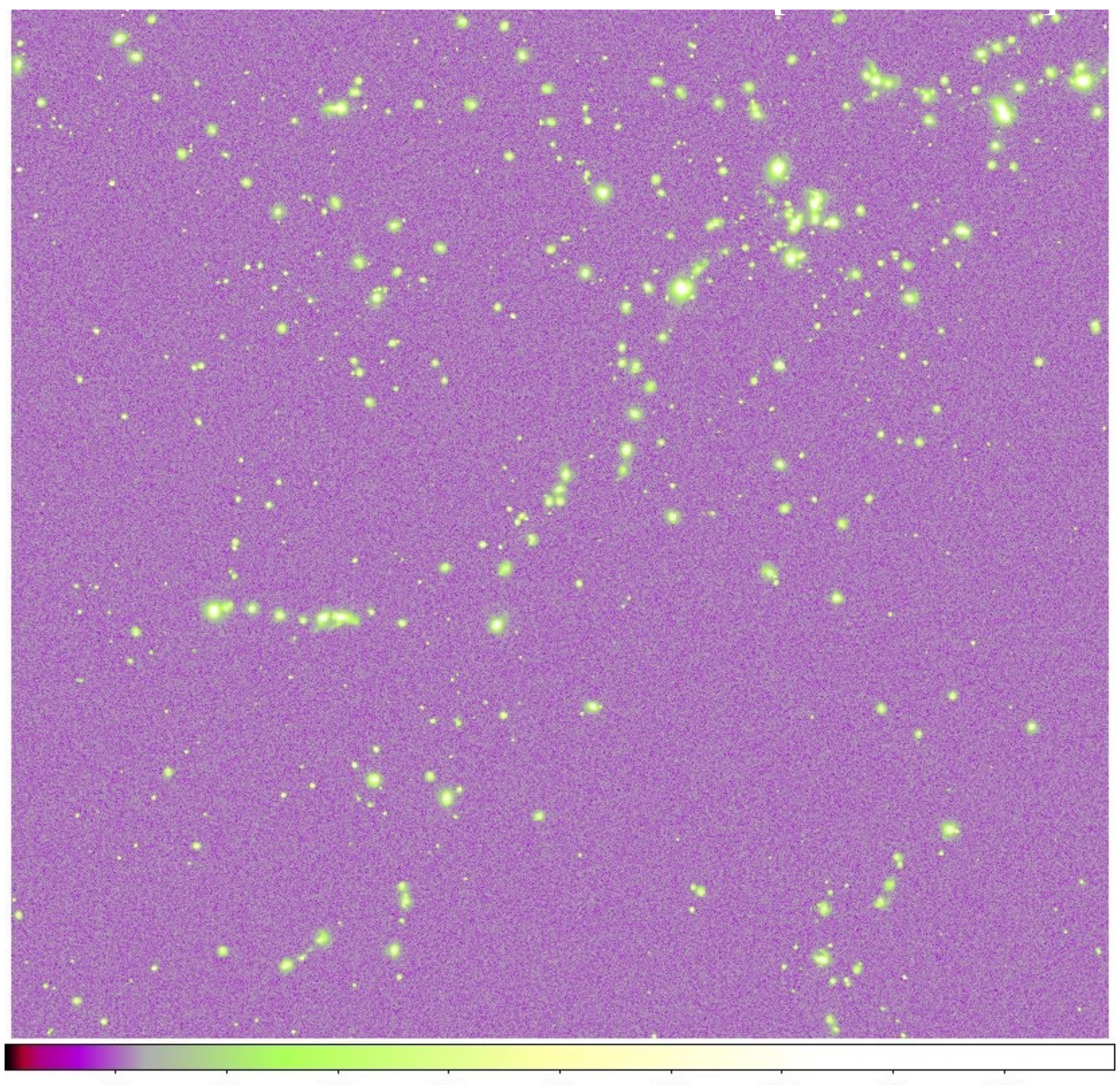
Bg = 2900 cnts/Ms/$arcmin^2$, nH=2 10^{20} cm^2

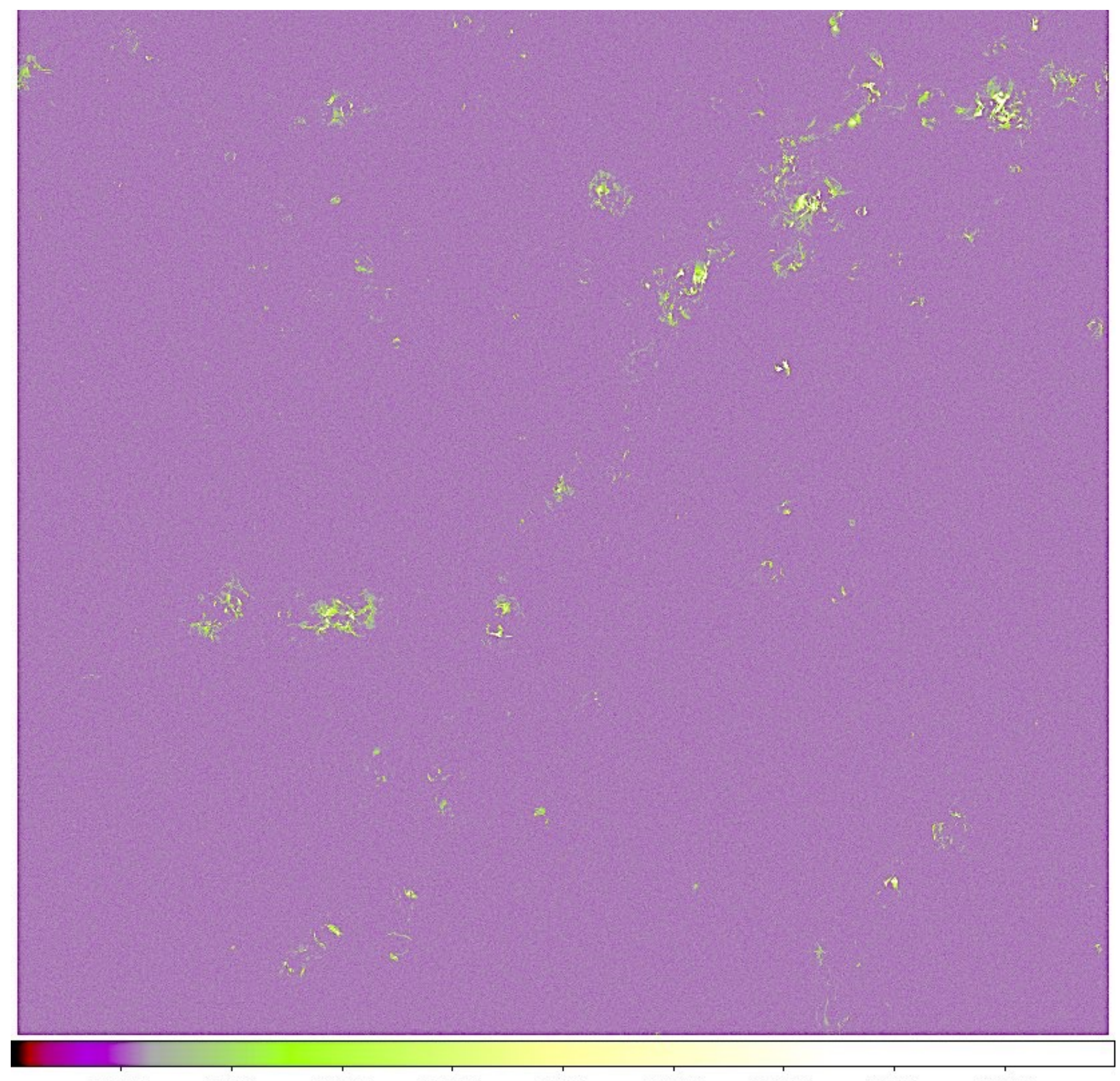
SKA-LOW (“Bmax=45km”)

ν~260 MHz assuming a <u>2yr survey</u>

beam= 10” , confusion noise: σ~20μJy/beam

no gal.foreground, no galaxy contribution





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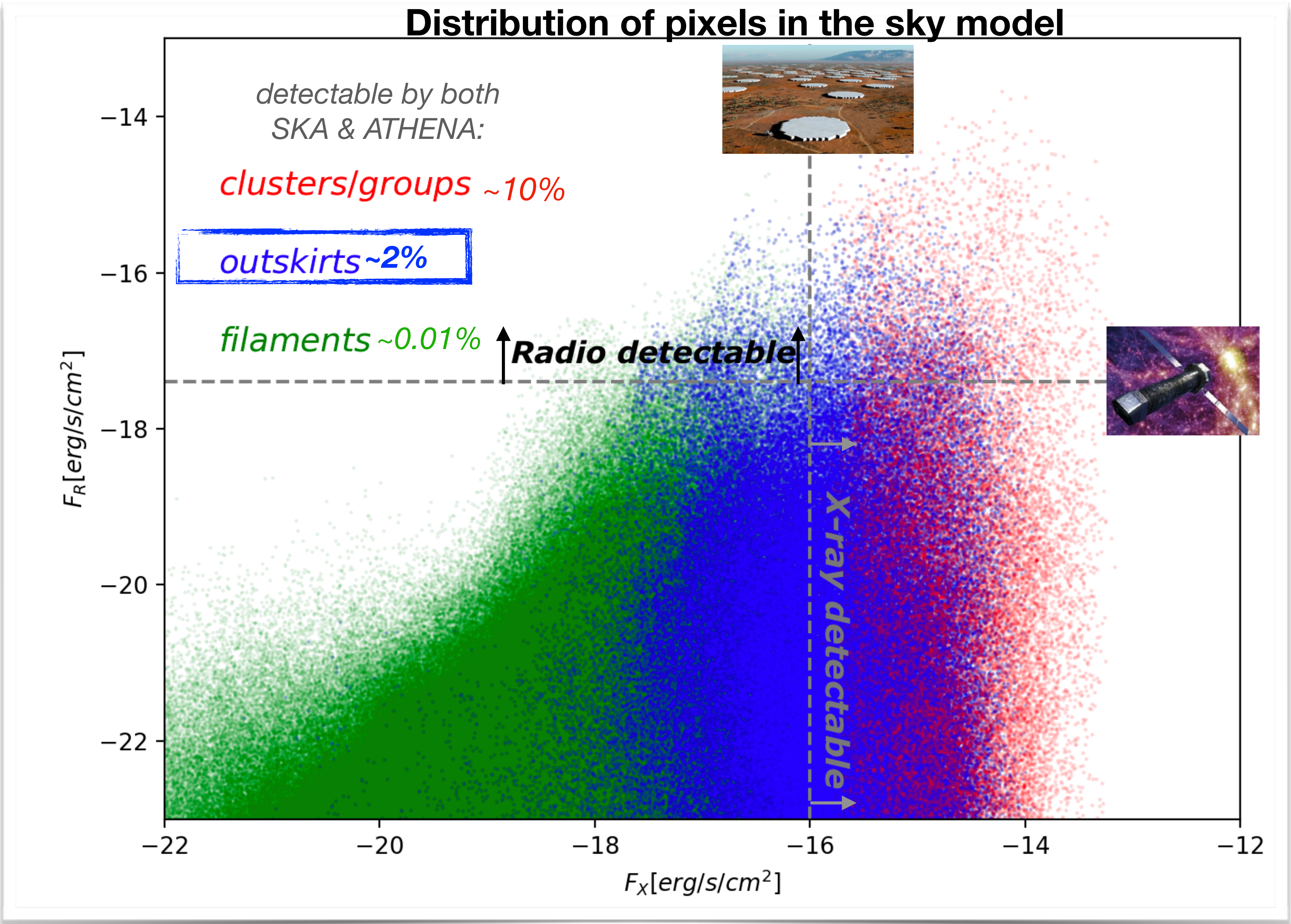


Athena-SKA White Book.

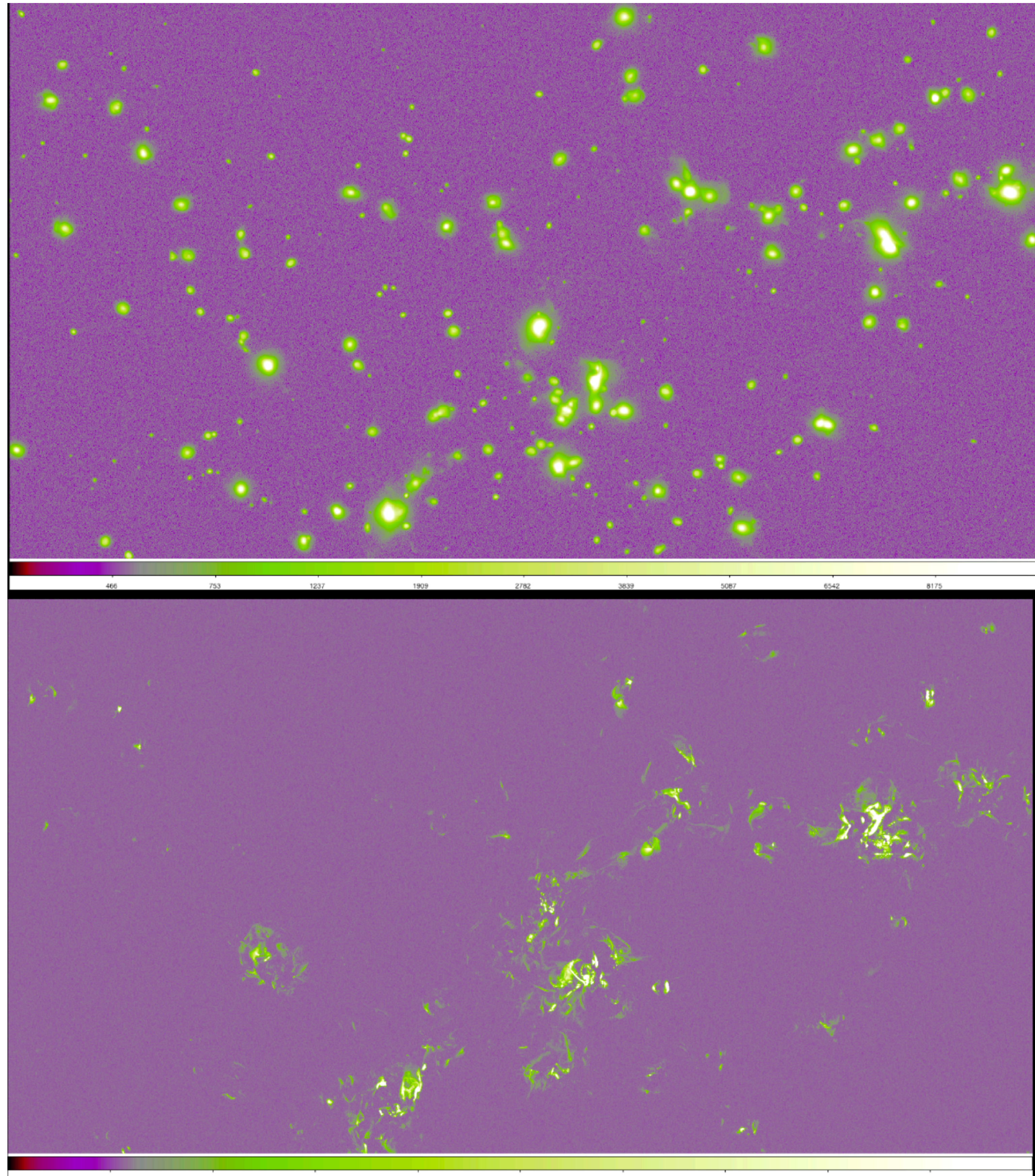
SKA & ATHENA: SYNERGIES ON THE COSMIC WEB

(FV, Ettori, Roncarelli, Angelinelli, Gheller+ to be sub.)

- At ~R100 in galaxy clusters there is ~2-3% changes of “double detection”

- How to best invest a **1Ms observation** with Athena’s XIFU (~2031), based on SKA (~2026) detections?

- Can we detect the **WHIM *in emission*** in these objects? What science can we do with this?



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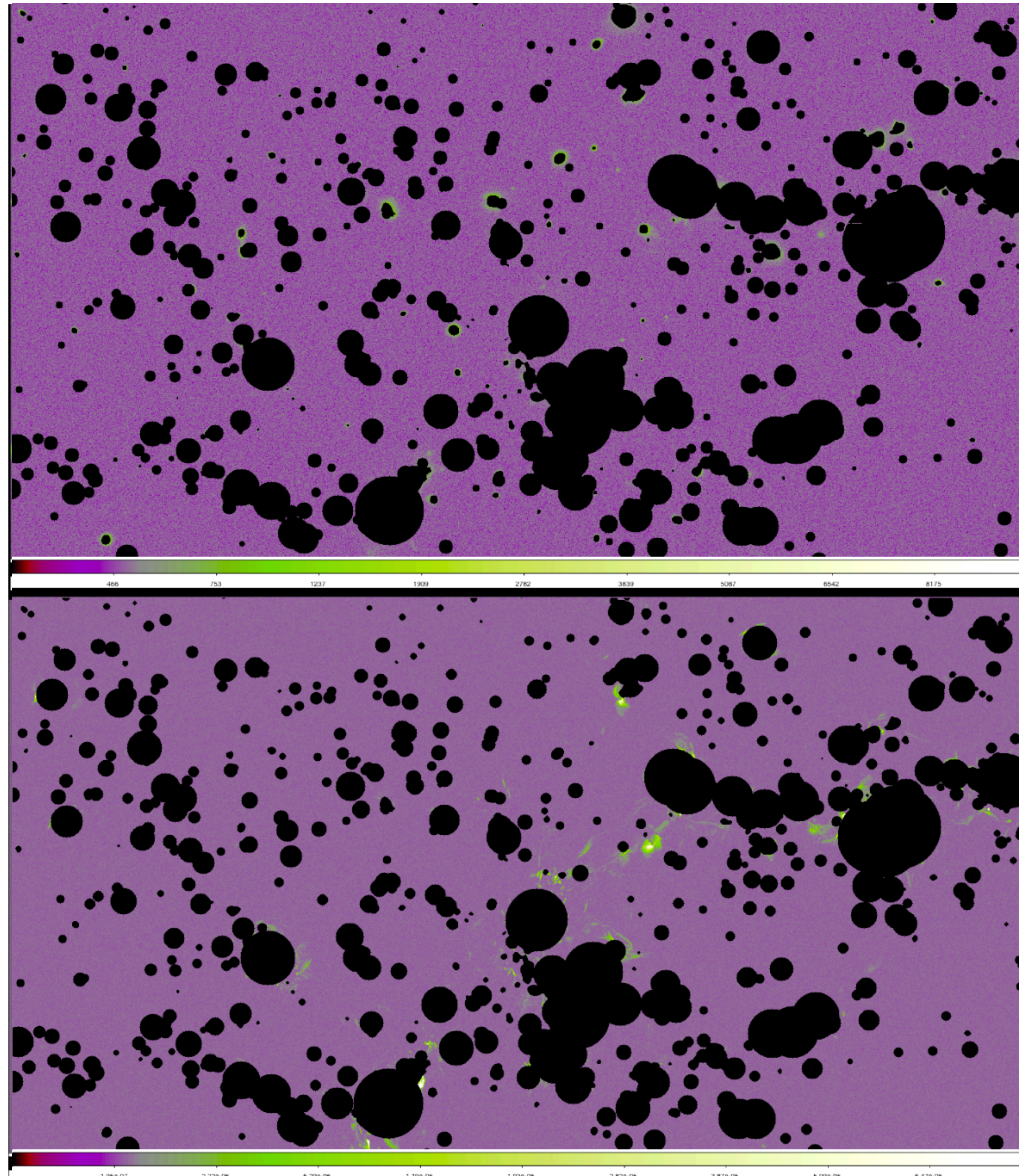


Athena-SKA White Book.

SKA & ATHENA: SYNERGIES ON THE COSMIC WEB

(FV, Ettori, Roncarelli, Angelinelli, Gheller+ to be sub.)

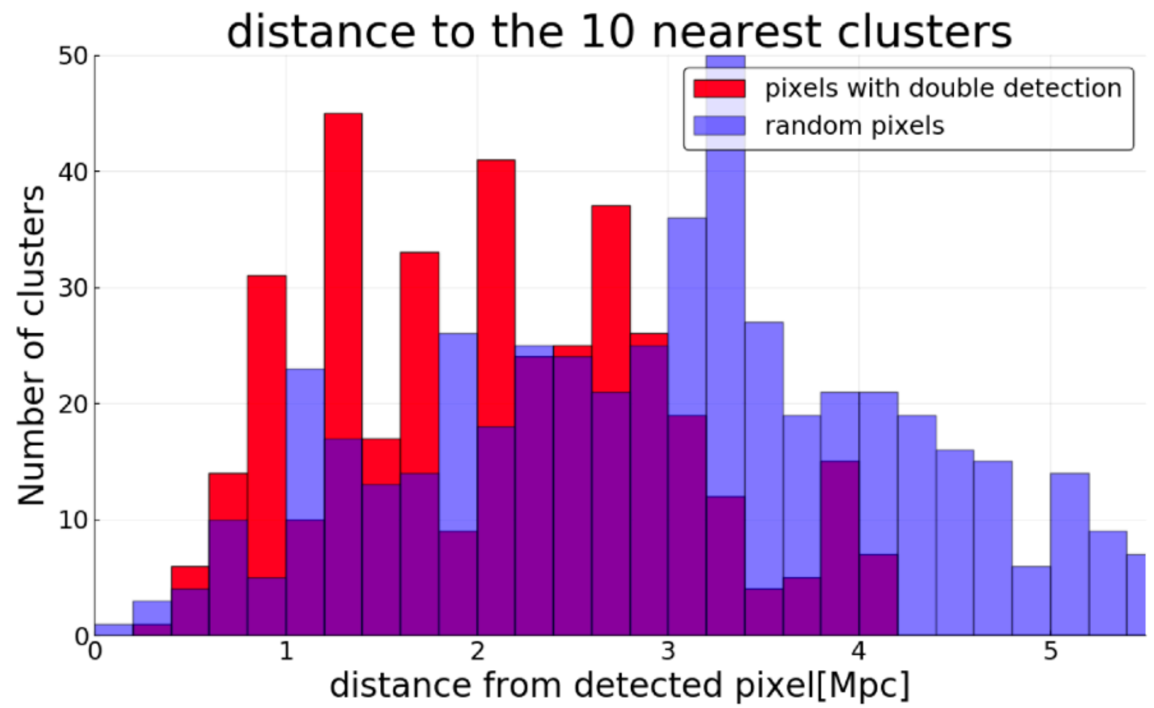
"Doubly detectable" regions are found in

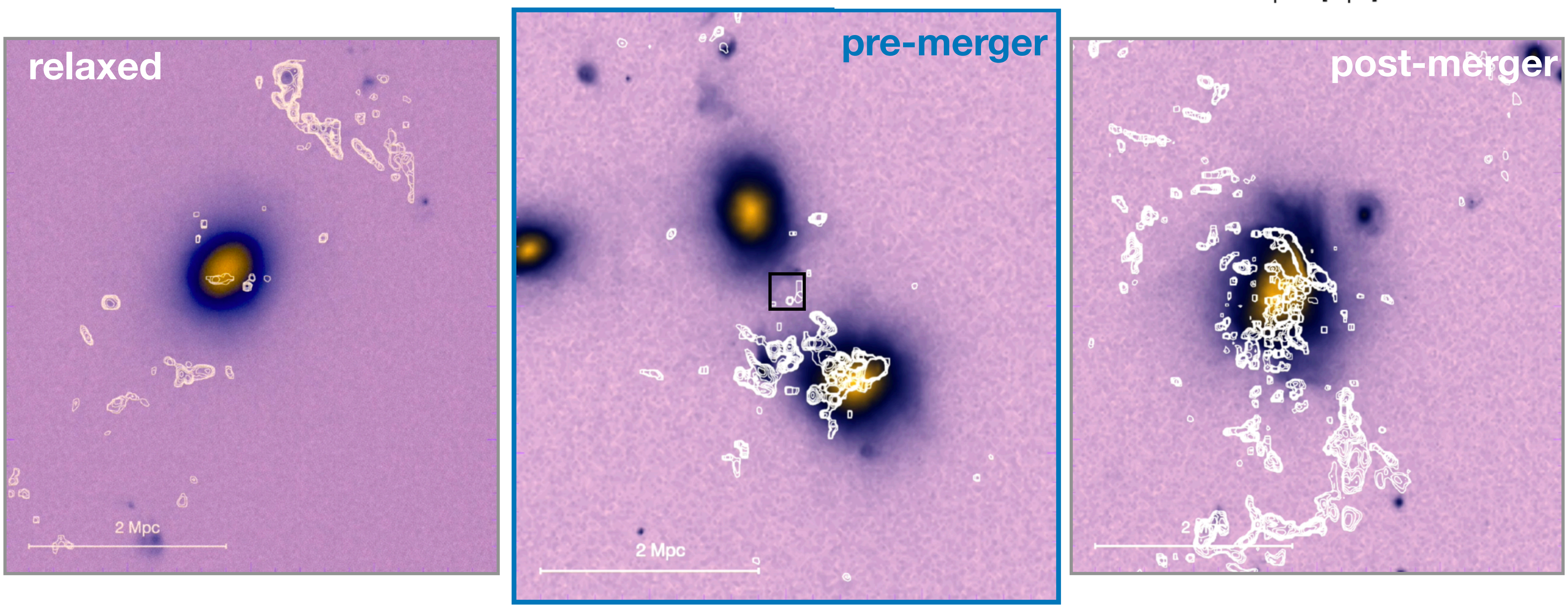
- a crowded environment

In typically **pre-merger** galaxy clusters with:

- **$>3\ 10^{14}\ M_0$** masses and
- **$d_{3D} > 2R_{100}$** separations.

The gas there is compressed up to ~ICM values, but is entering clusters for the first time (*boosted WHIM!*)





THE “BOOSTED” WHIM IN PRE-MERGER CLUSTERS

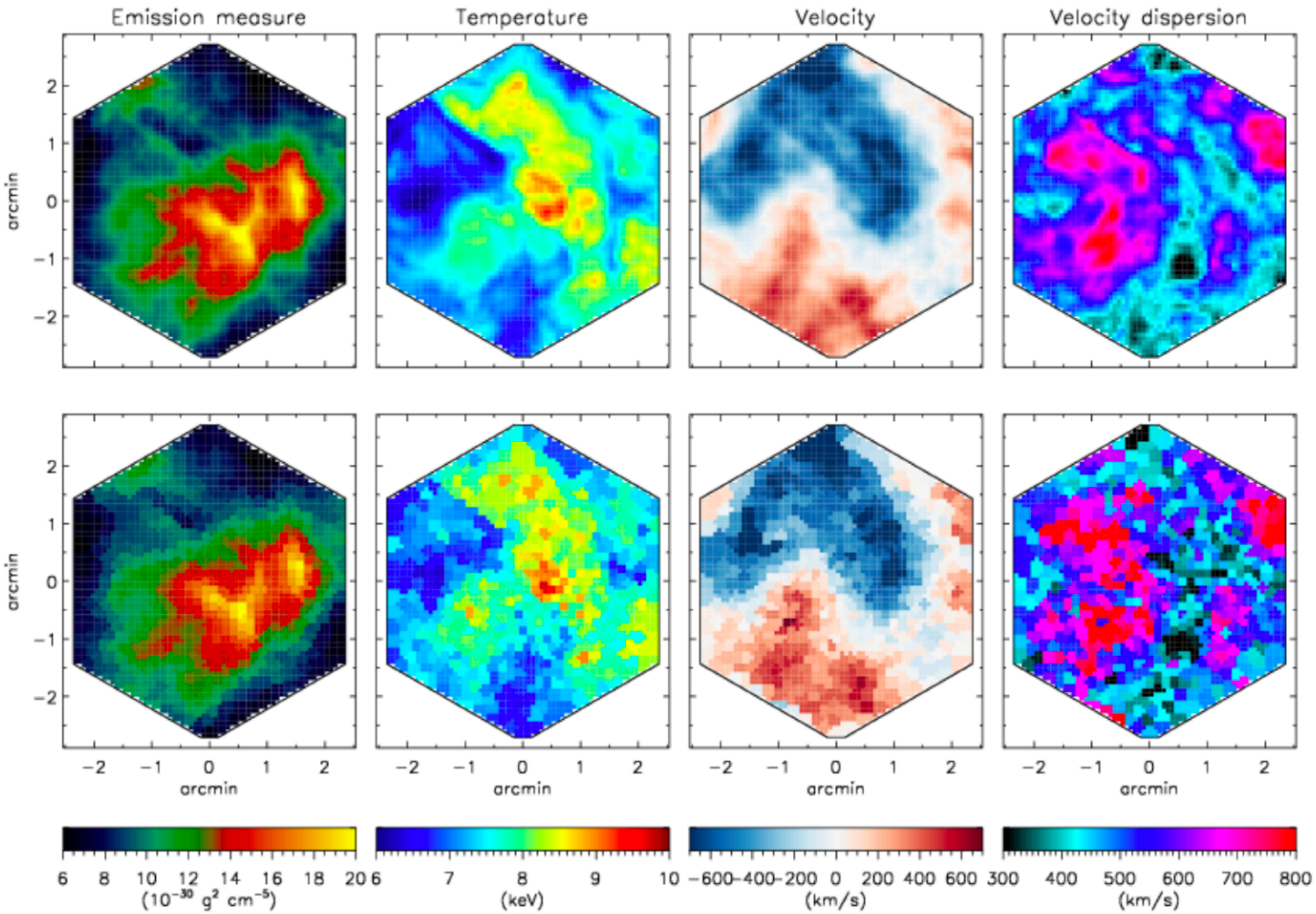
(FV, Ettori, Roncarelli, Angelinelli, Gheller+ to be sub.)

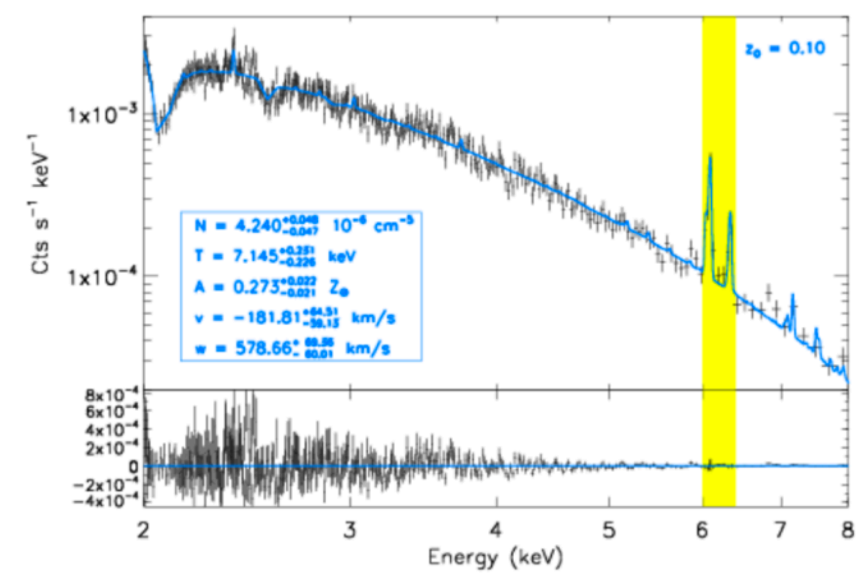
*(**Dominguez-Fernandez**, FV, Bruggen & Brunetti to be sub.)*

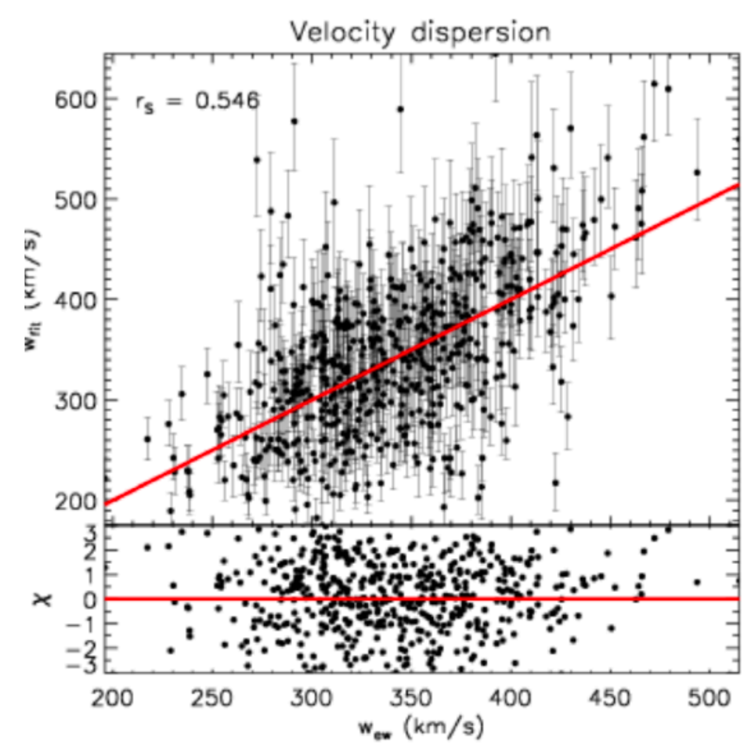
SKA & ATHENA: SYNERGIES ON THE COSMIC WEB

*(**Roncarelli**, Gaspari, Ettori+ 2018 MNRAS)*

Interlude: Simulated XIFU analysis of intracluster turbulence (R<Mpc) using SIXTE







Good match between real and reconstructed parameters

Velocity dispersion correct within a ~15% error ($\sigma_v/c_s<0.75$)

Important for future tests of reacceleration scenarios for **radio halos**

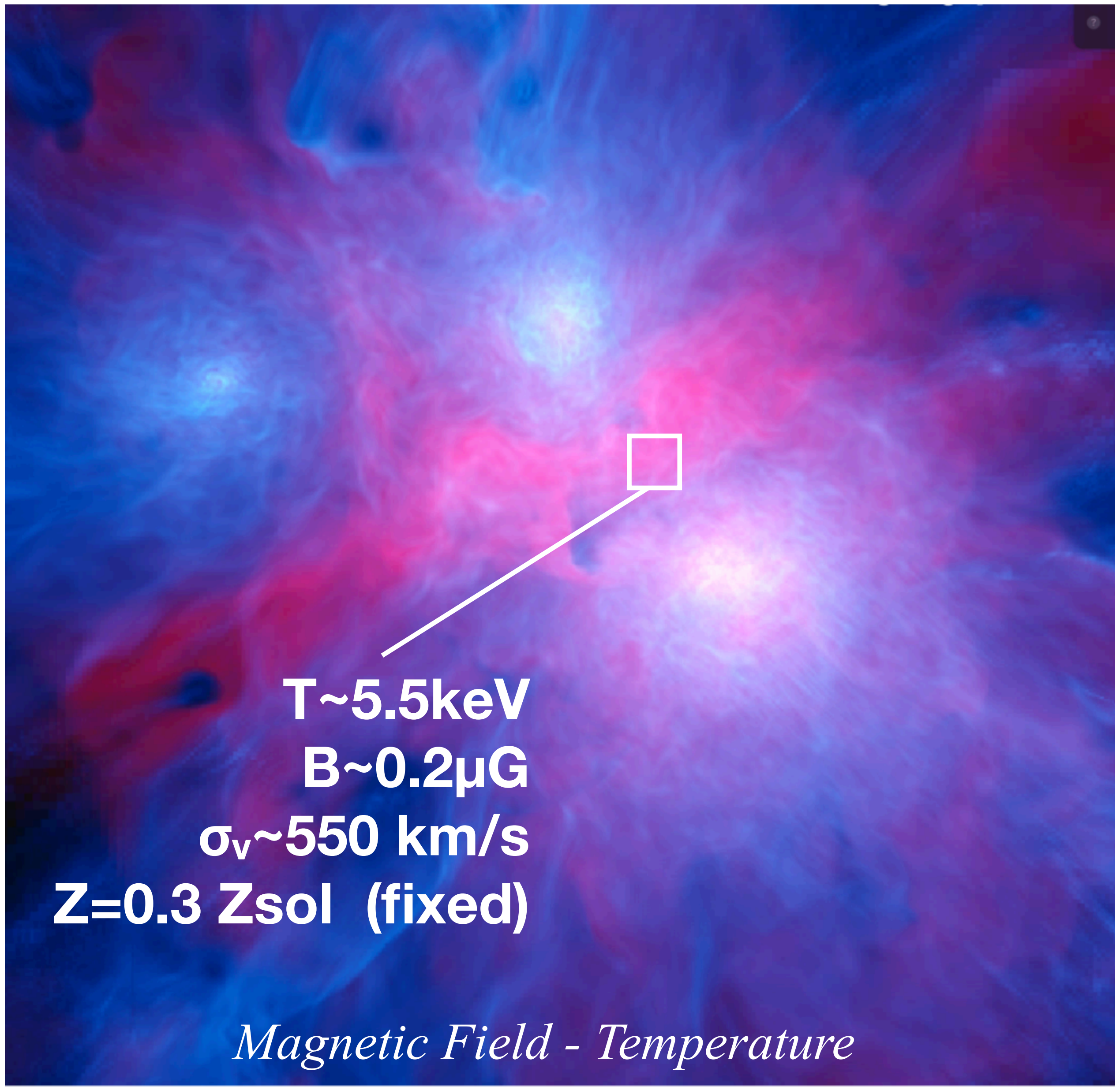
What can XIFU do in cluster bridges?

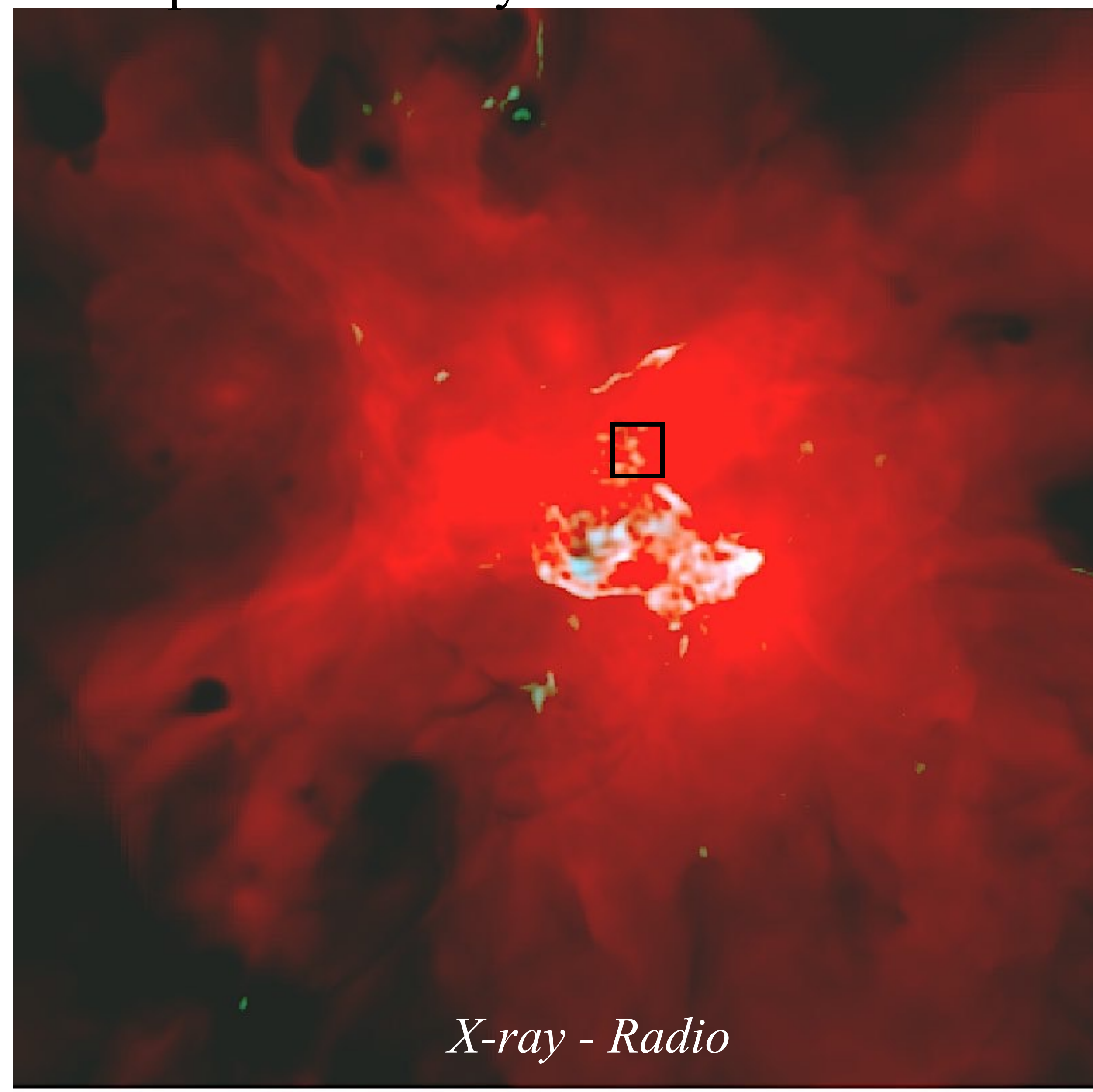
(see also Cassano et al., SKA-Athena Synergy White Paper)

SKA & ATHENA: SYNERGIES ON THE COSMIC WEB

(FV, Ettori, Roncarelli, Angelinelli, Gheller+ to be sub.)

Simulated 1Ms observation with XIFU on a ~5' patch visible by both instruments



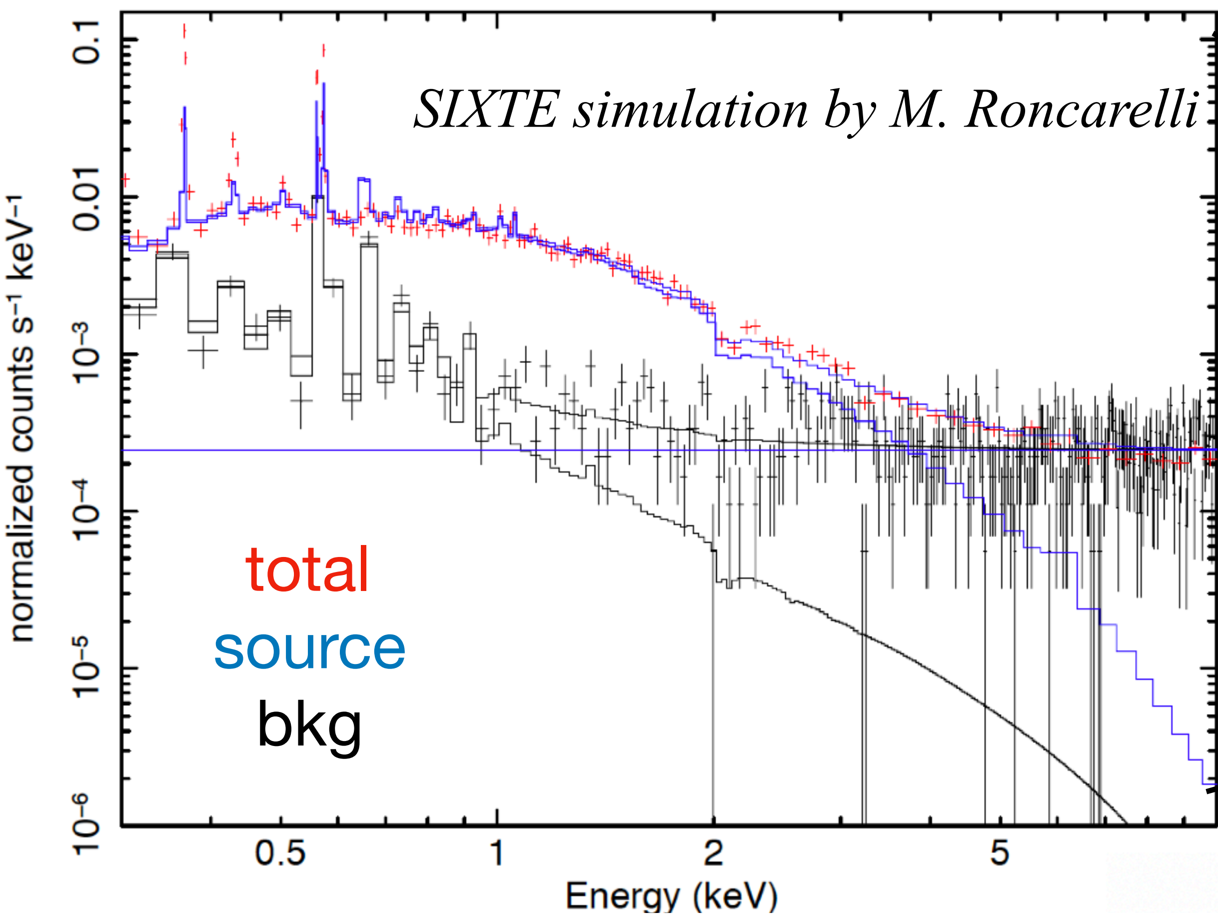


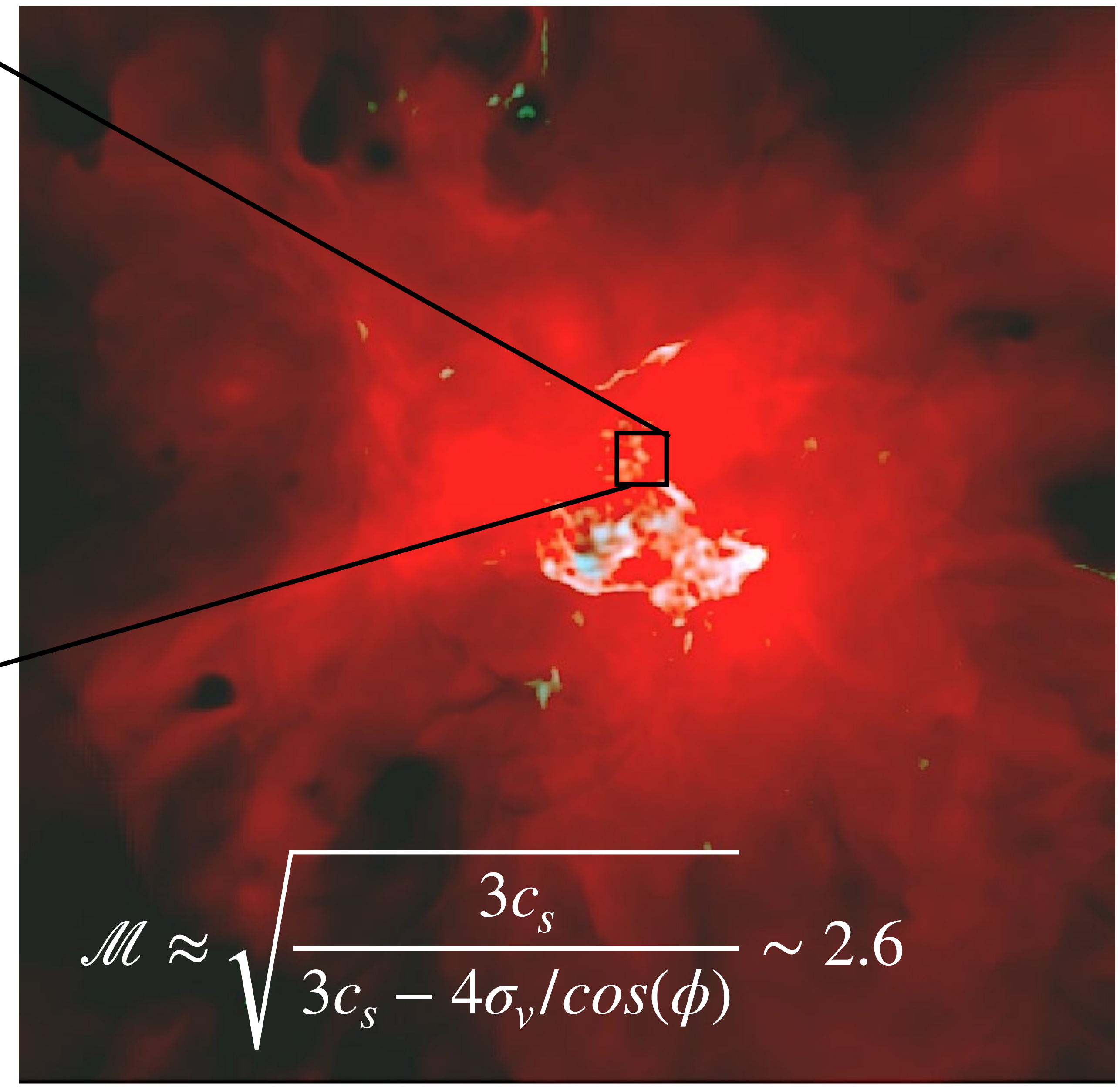
What will Athena and SKA teach us about intracluster bridges?

SKA & ATHENA: SYNERGIES ON THE COSMIC WEB

(FV, Ettori, Roncarelli, Angelinelli, Gheller+ to be sub.)

Simulated **1Ms** observation with XIFU (res=2”, ΔE=2eV, FOV=5’)





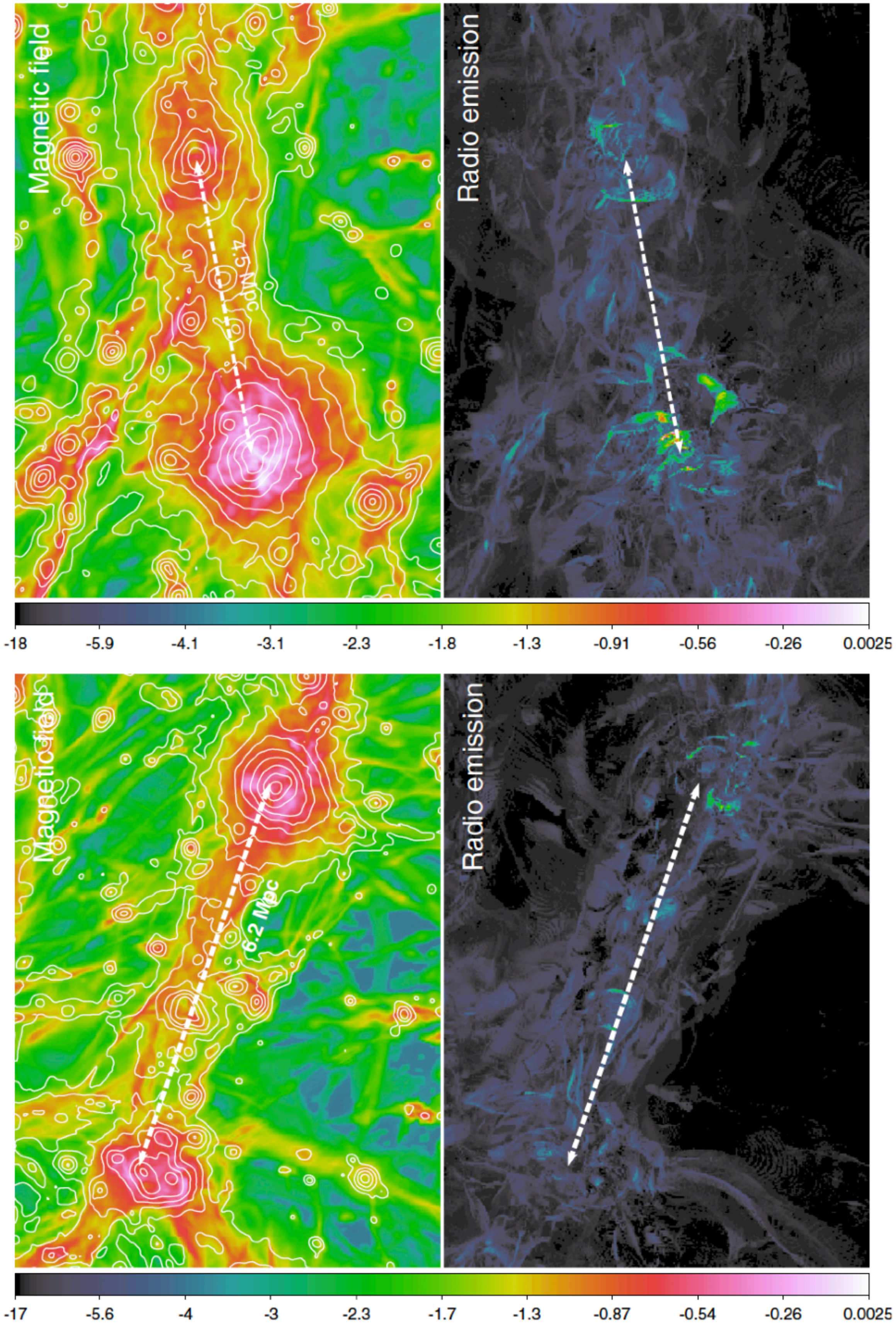
Input		Reconstructed	
T=5.52keV	→	*5.22*	*[4.92- 5.53]*
Z=0.3 Zsol		*0.2*	*[0.16-0.25]*
σ_v~550 km/s		*444*	*[305.27-592.47]*

Gas velocity dispersion and thermodynamic parameters well reconstructed with a 1Ms integration.

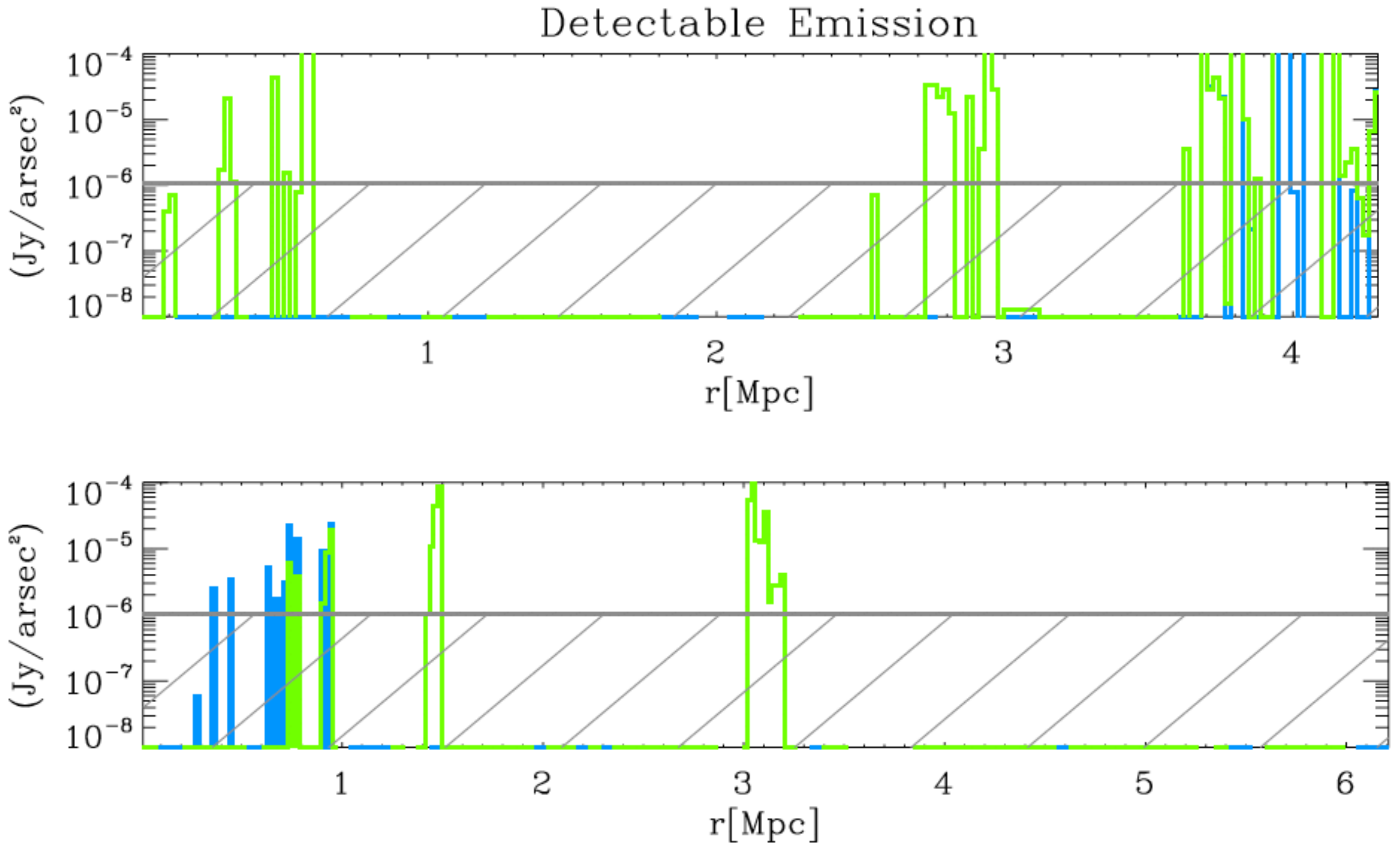
Potentially a new method to estimate shock strength and acceleration efficiency in cluster outskirts(?)

THE COSMIC WEB IN THE RADIO WINDOW : LOFAR-LBA/HBA

(FV, Ferrari, Bonafede+ 2015 A&A)



LOFAR HBA should be (already) able to detect emission in **intracluster filaments/bridges**



These shocks should be weaker than accretion ones (M~5) and **transient**

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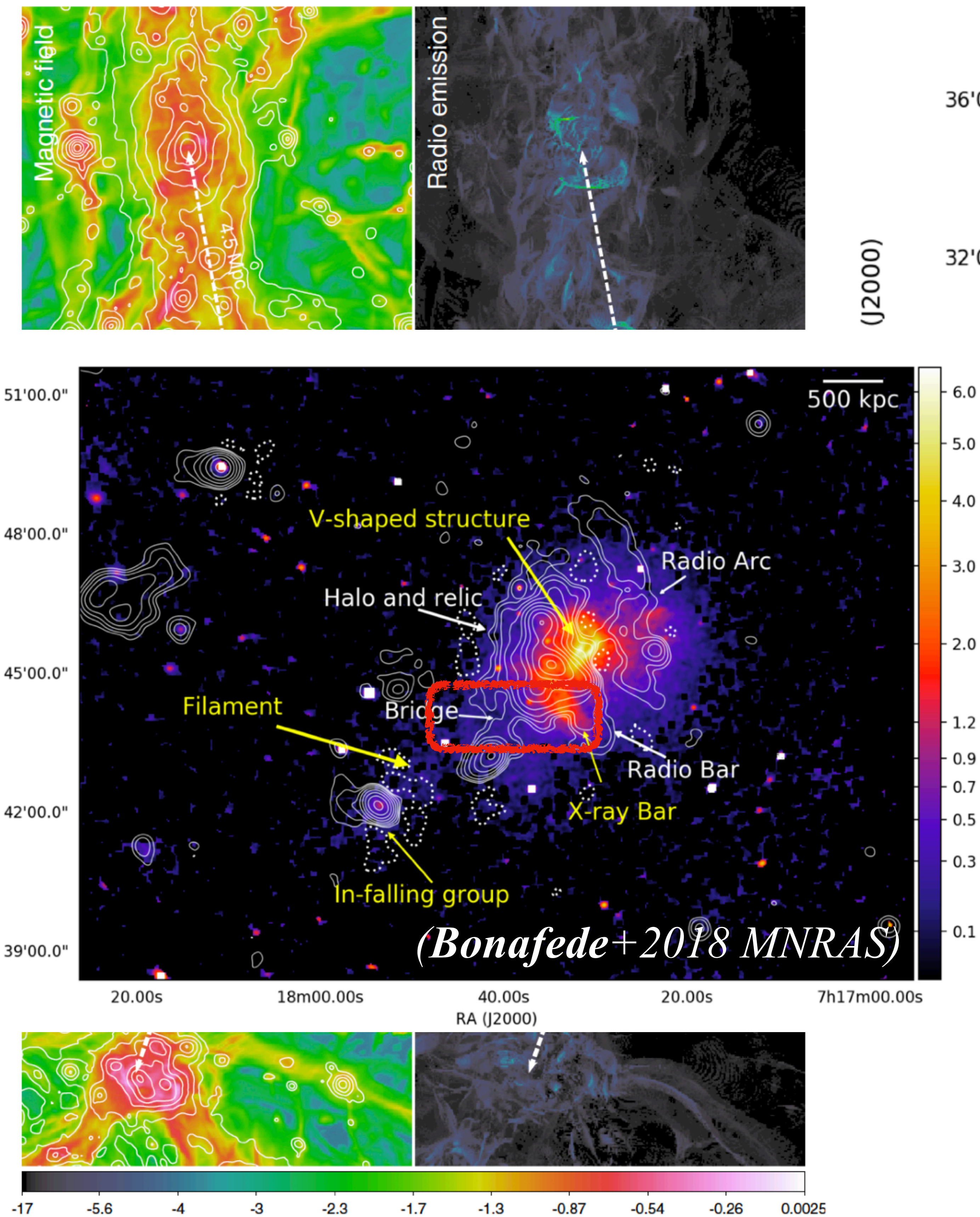
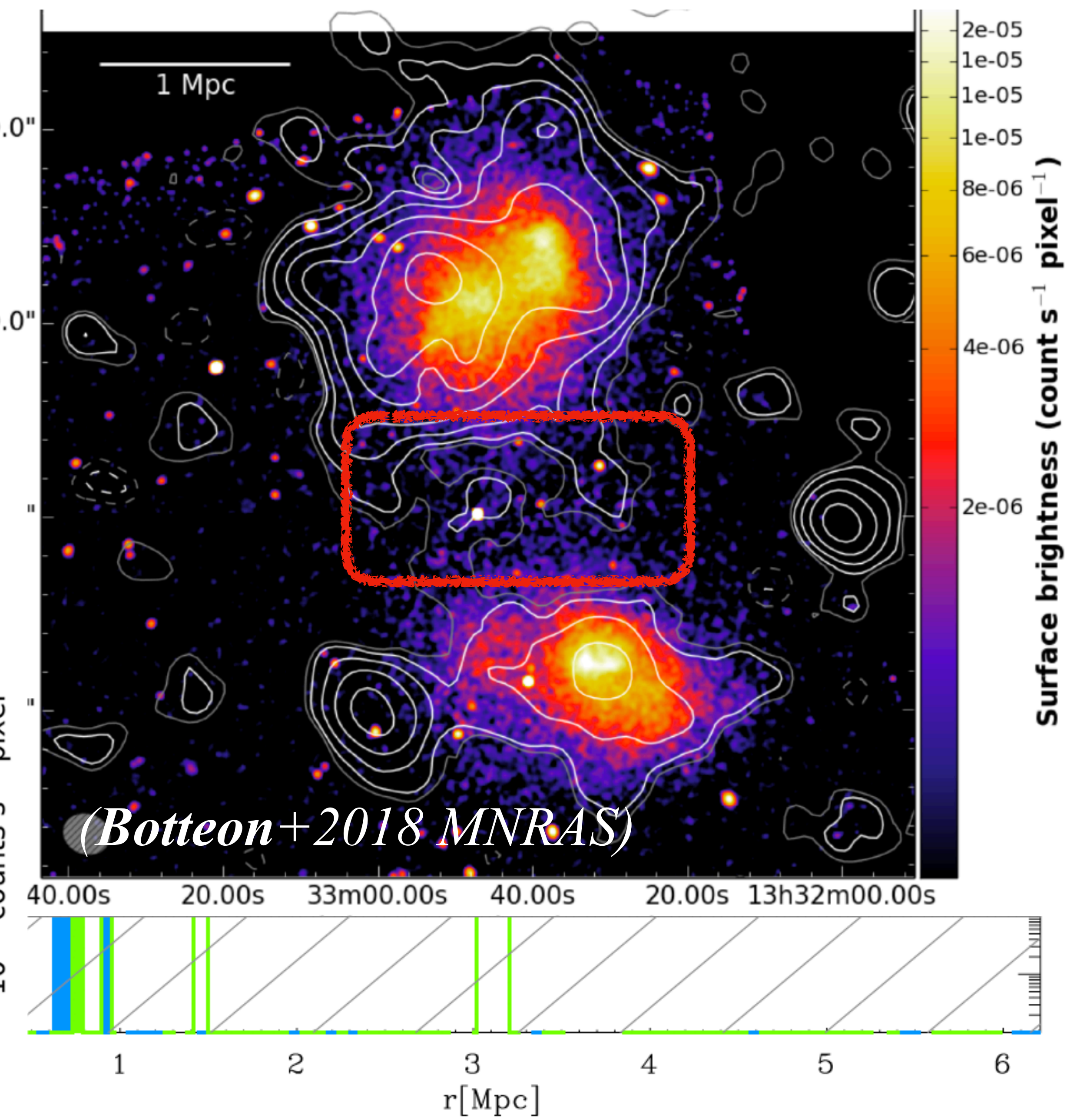
(FV, Ferrari, Bonafede+ 2015 A&A)





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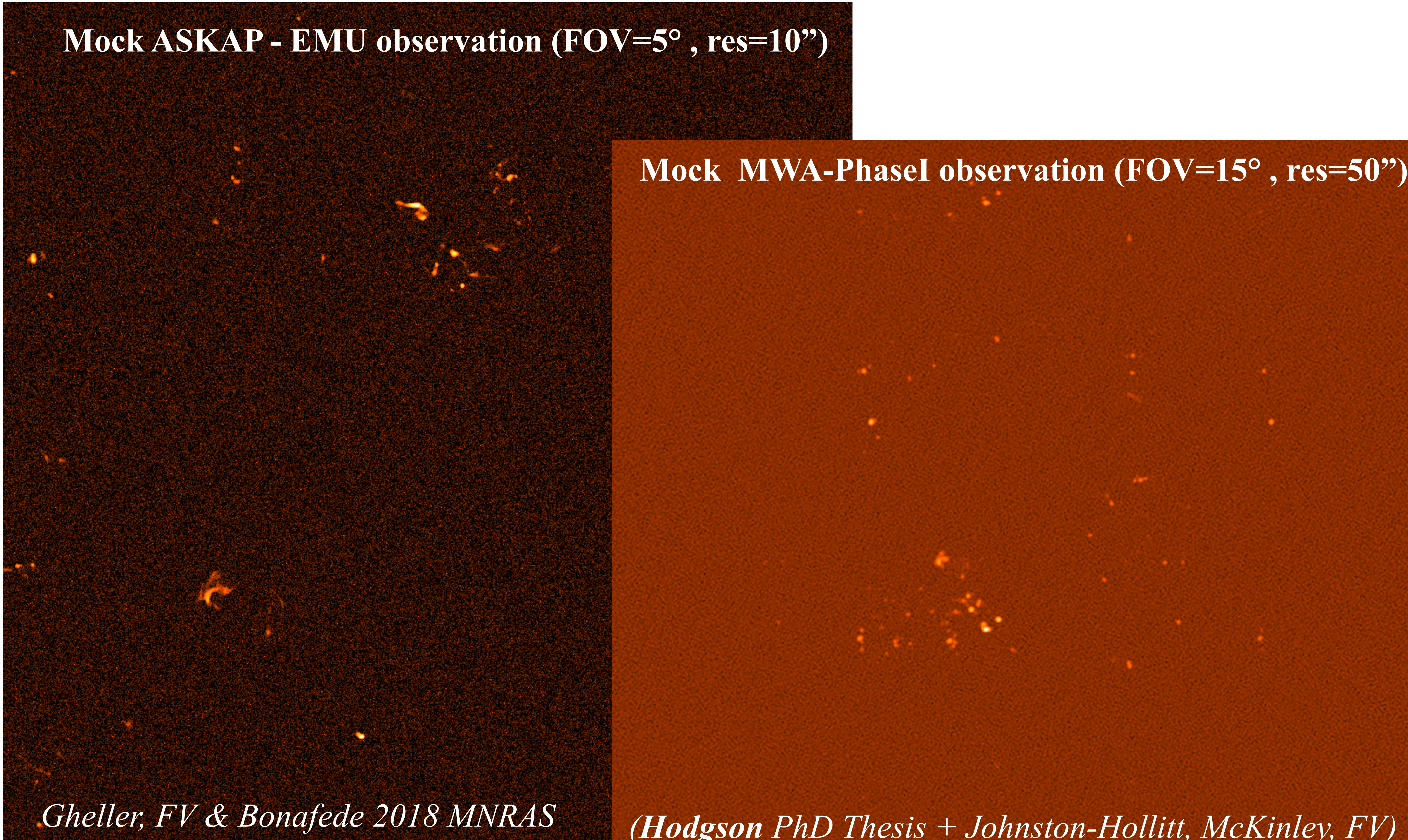
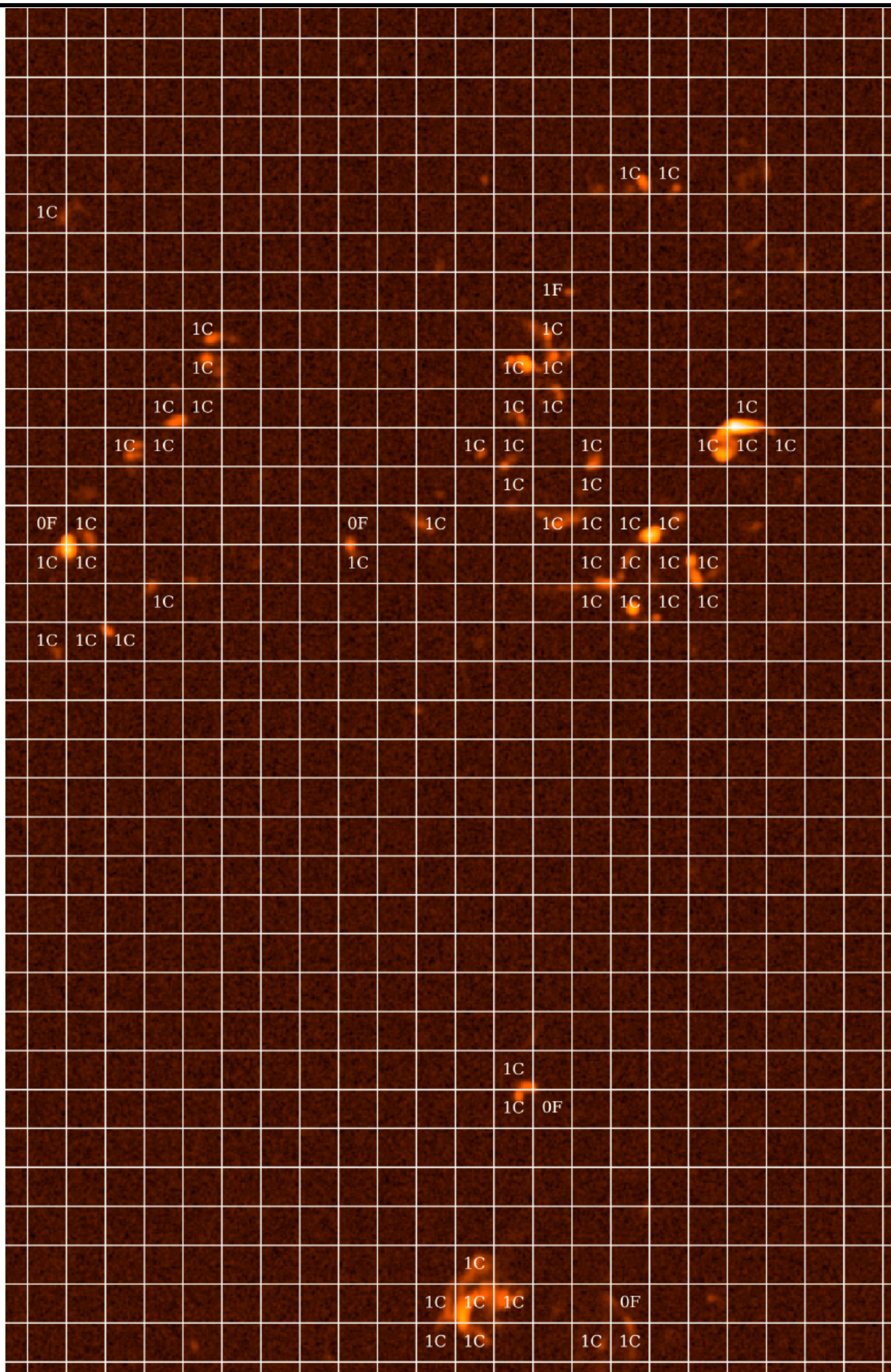
THE COSMIC WEB IN LARGE SURVEYS: A NEEDLE IN A HAYSTACK?

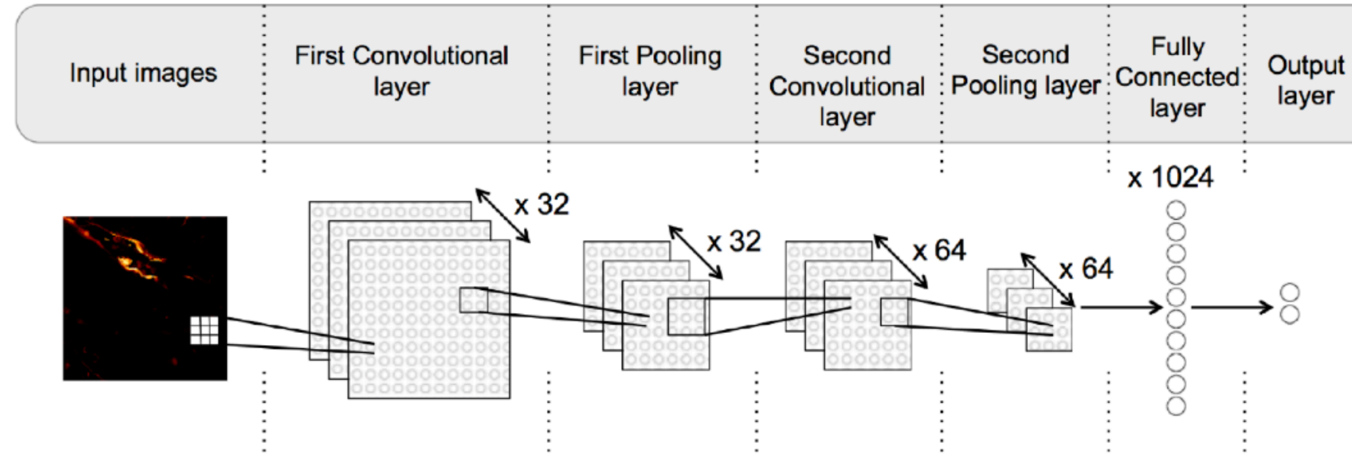


(see also Vacca+2018 for SRT mock observations)

COSMODEEP: A FAST, MACHINE LEARNING ALGORITHM TO DETECT DIFFUSE EMISSION

(Gheller, FV, Bonafede 2018 MNRAS)





trained on 10,000 mock images

~0.1s/image (2000 x 2000 pixels images)

~90% correct identification **down ~1σ_{rms}**

More performing than PyBDSF for <3σ_{rms}

(of course, *idealized setup*)

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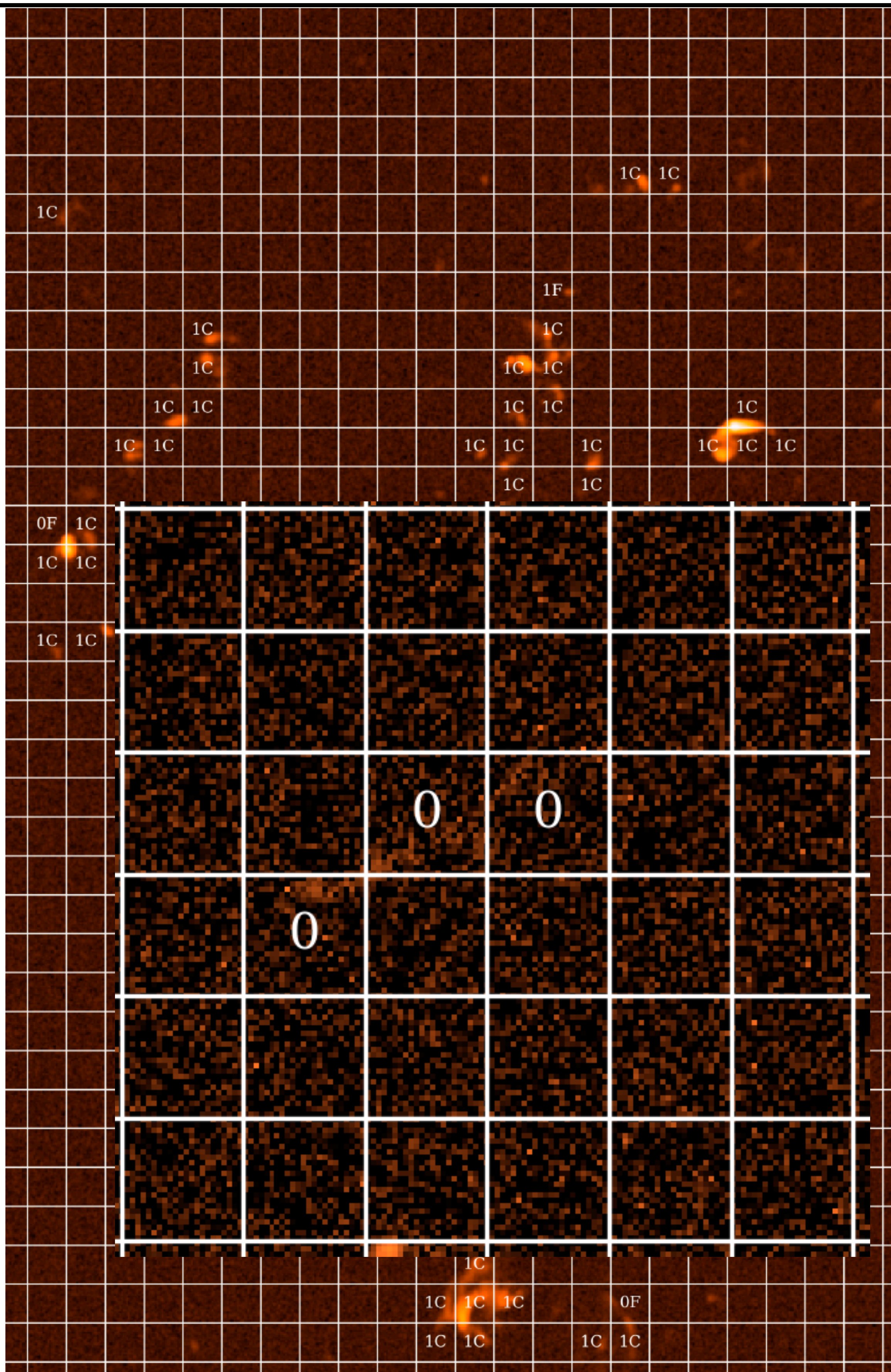

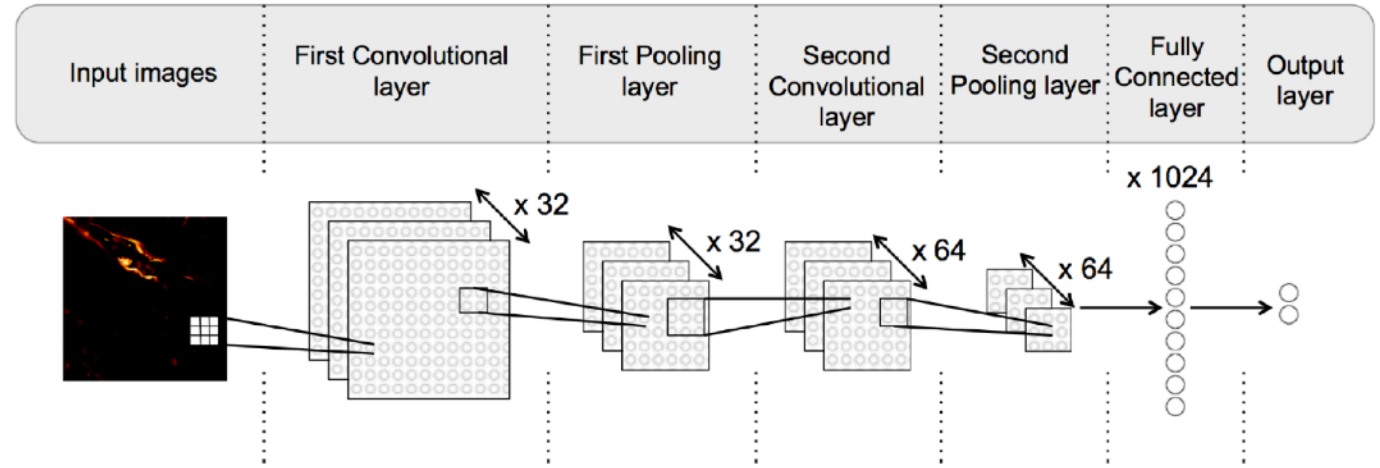

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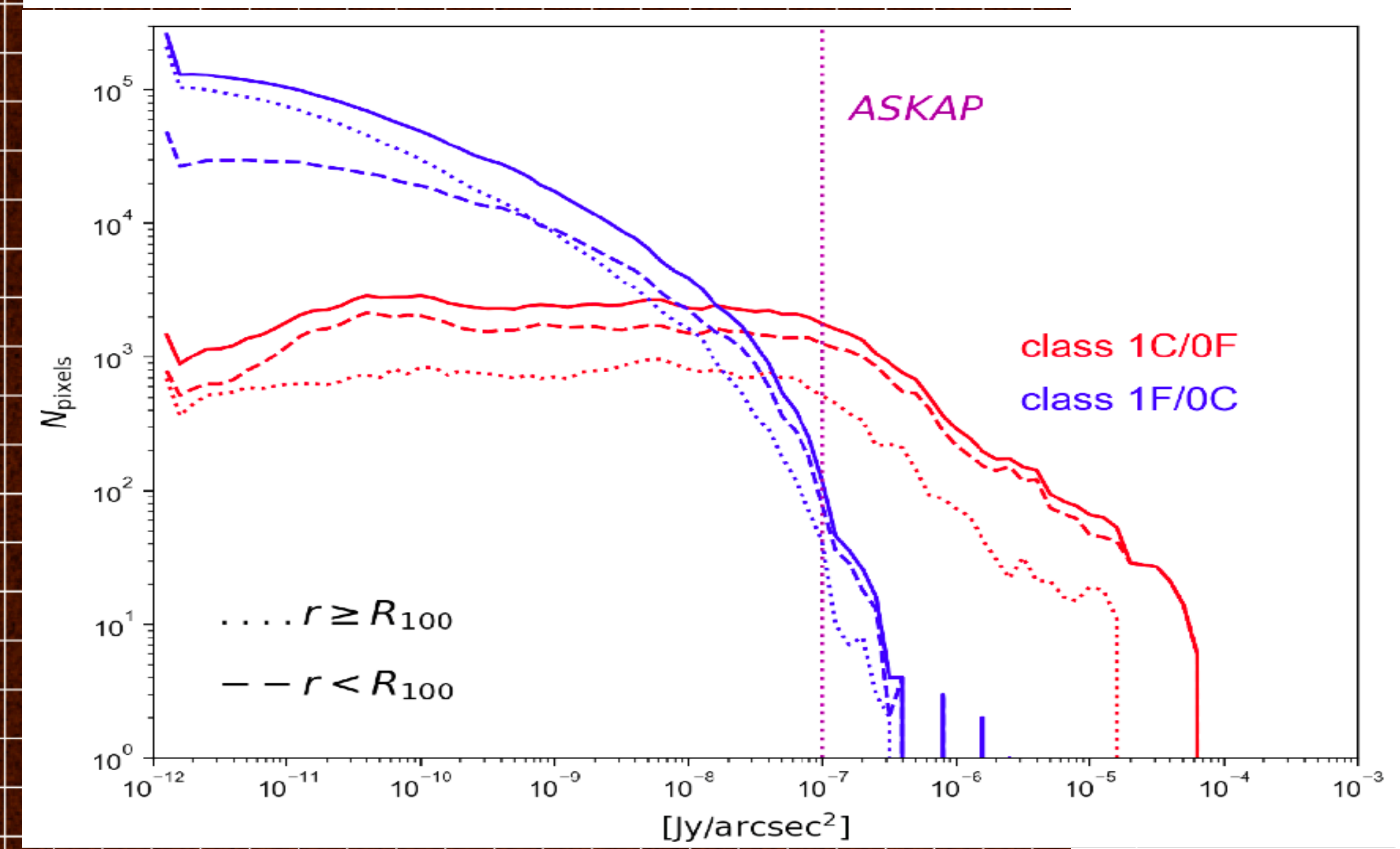
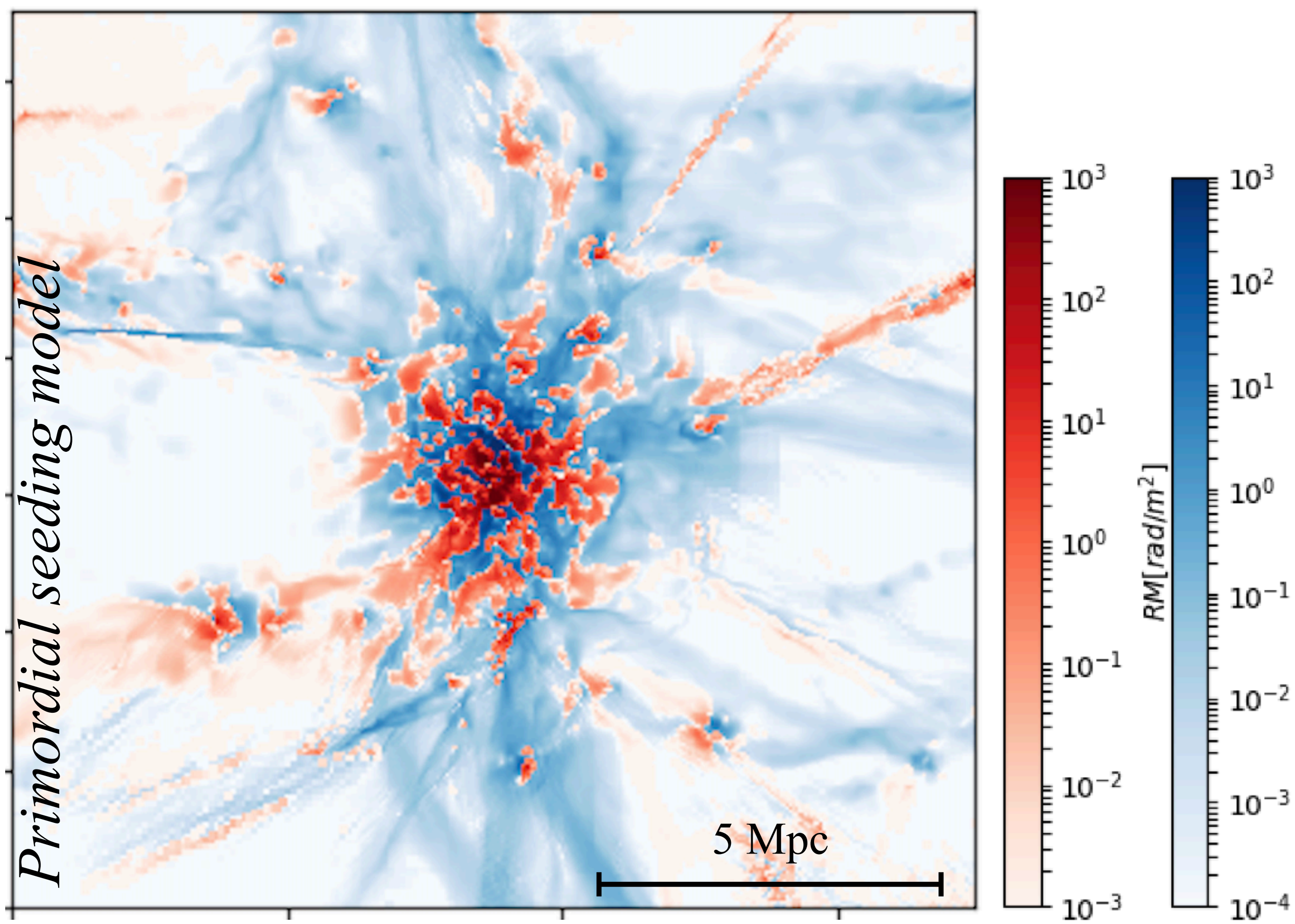
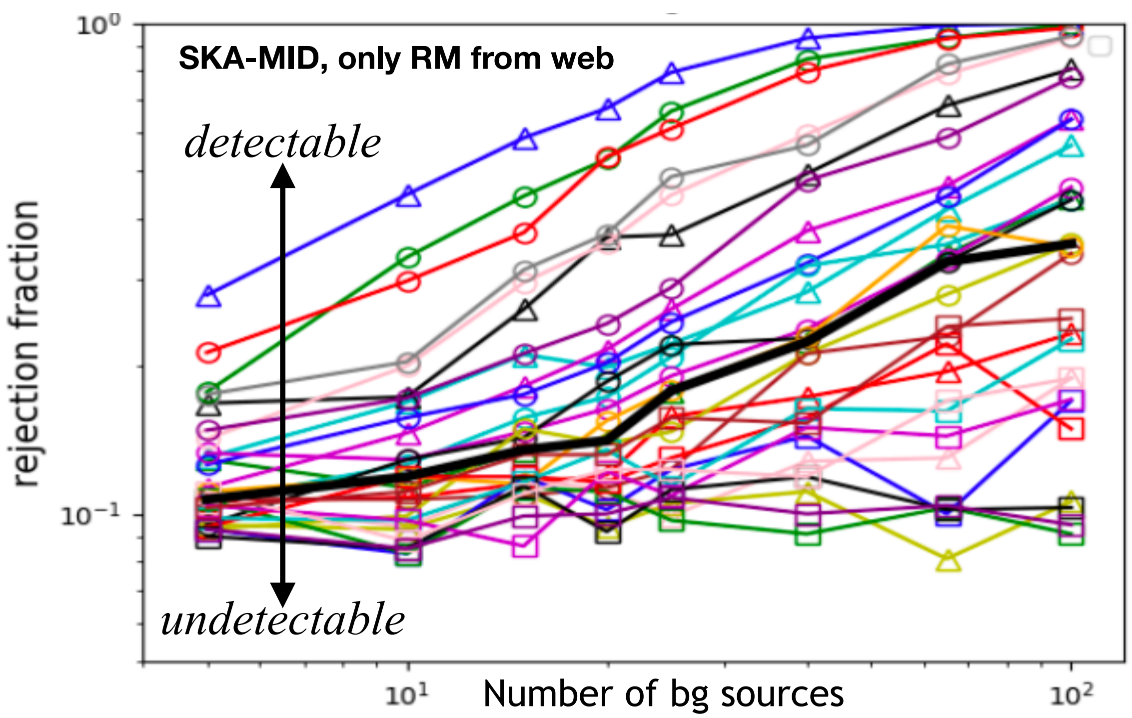
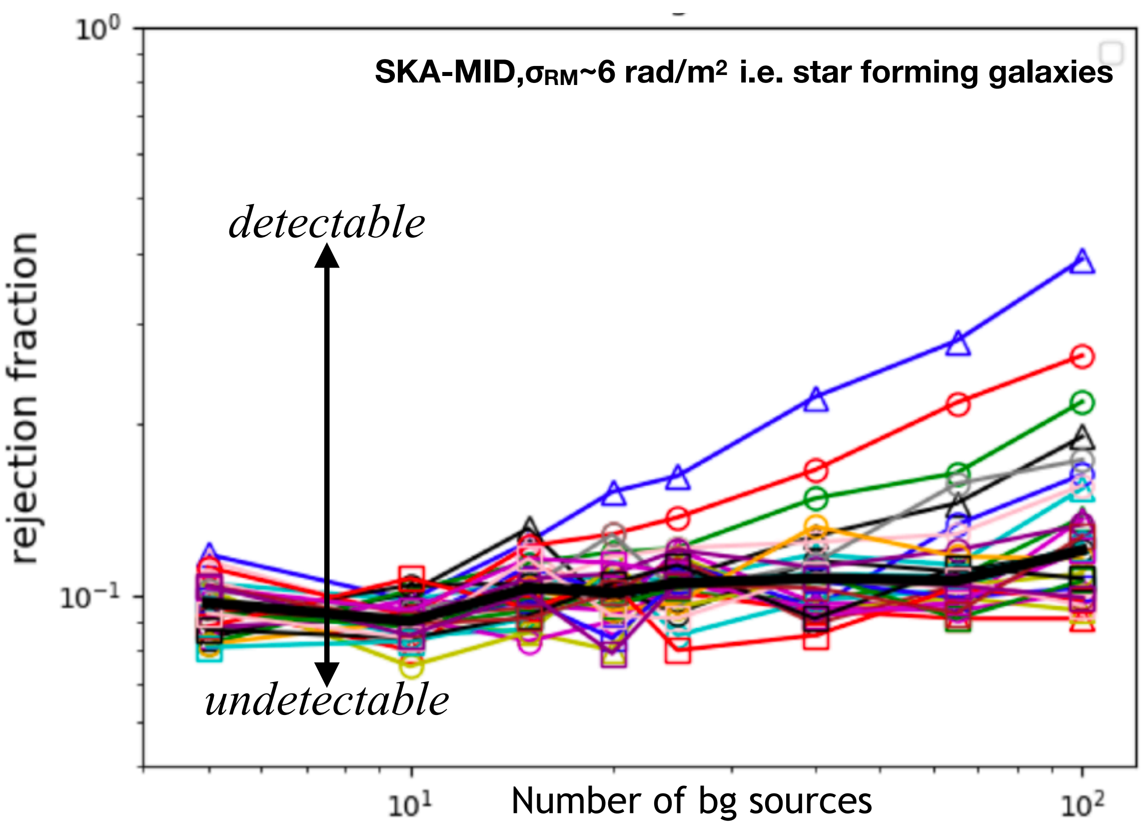


DETECTING INTRACLUSTER FILAMENTS WITH FARADAY ROTATION

*(**Locatelli**, FV, Dominguez-Fernandez 2018 Galaxies)*







*The **SKA-MID** will probe RM in a critical regime to distinguish primordial from astrophysical models (~1-10 rad/m²)*

however, having the contamination from RM intrinsic to sources (σ_{RM}~6-12 rad/m²) under control will be crucial.

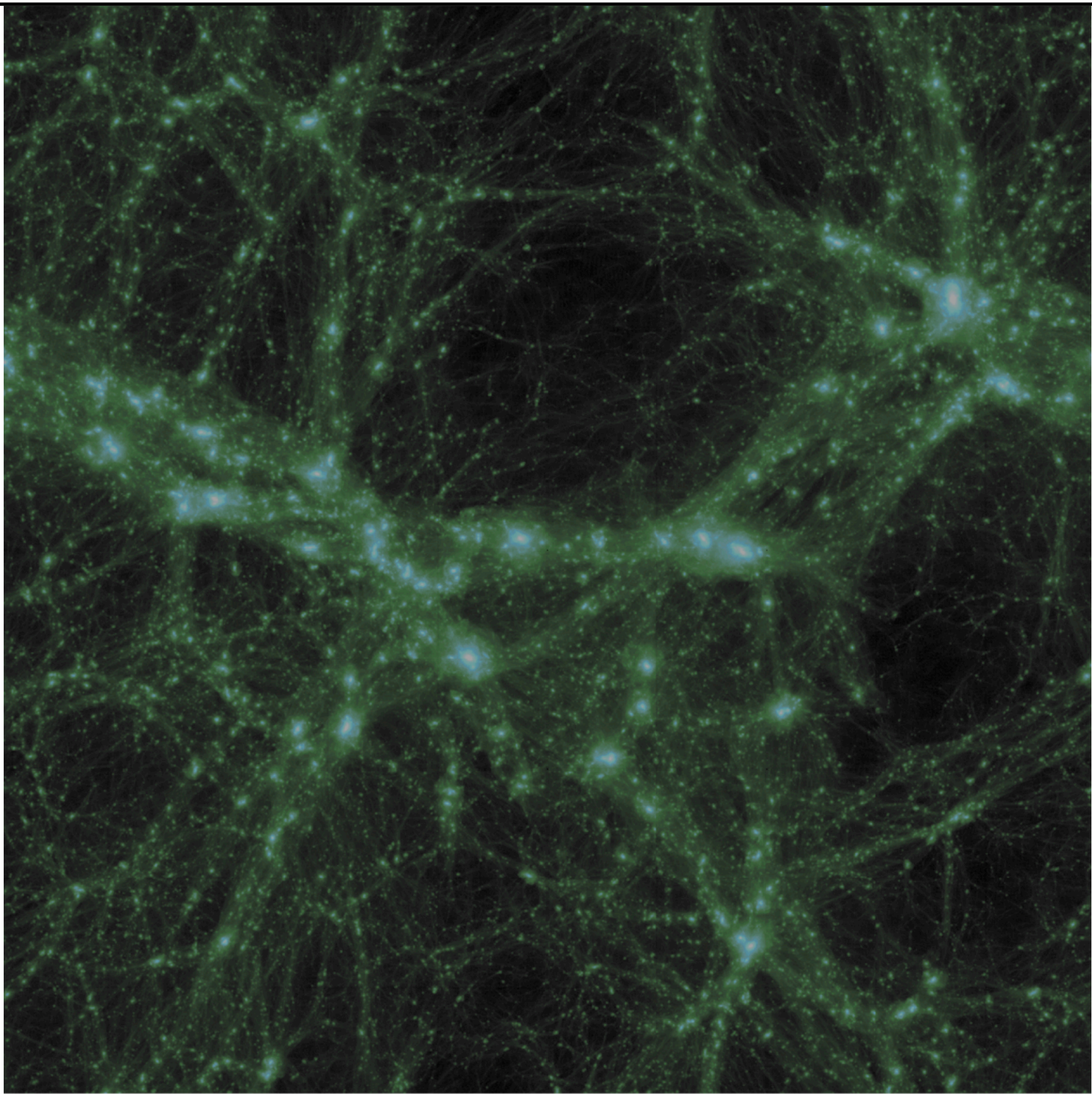
(see also Akahori et al. 2010, Vacca+2016)

CONCLUSIONS

- The cosmic web: likely the solution to the riddle of **missing baryons** and **magnetogenesis**

- **Low-frequency radio** observations give us the best chance to image the cosmic web

- Double detections of cluster bridges, guided by **SKA** detections, will give **ATHENA** the change of studying the WHIM in emission and explore extreme plasma conditions



CONCLUSIONS

- The cosmic web: likely the solution to the riddle of **missing baryons** and **magnetogenesis**
- **Low-frequency radio** observations are best to image the cosmic web, much more than X-ray
- Double detections of cluster bridges, guided by **SKA** detections, will give **ATHENA** the change of studying the WHIM in emission and explore extreme plasma conditions