1. The most powerful explosion in the Universe since the Big Bang

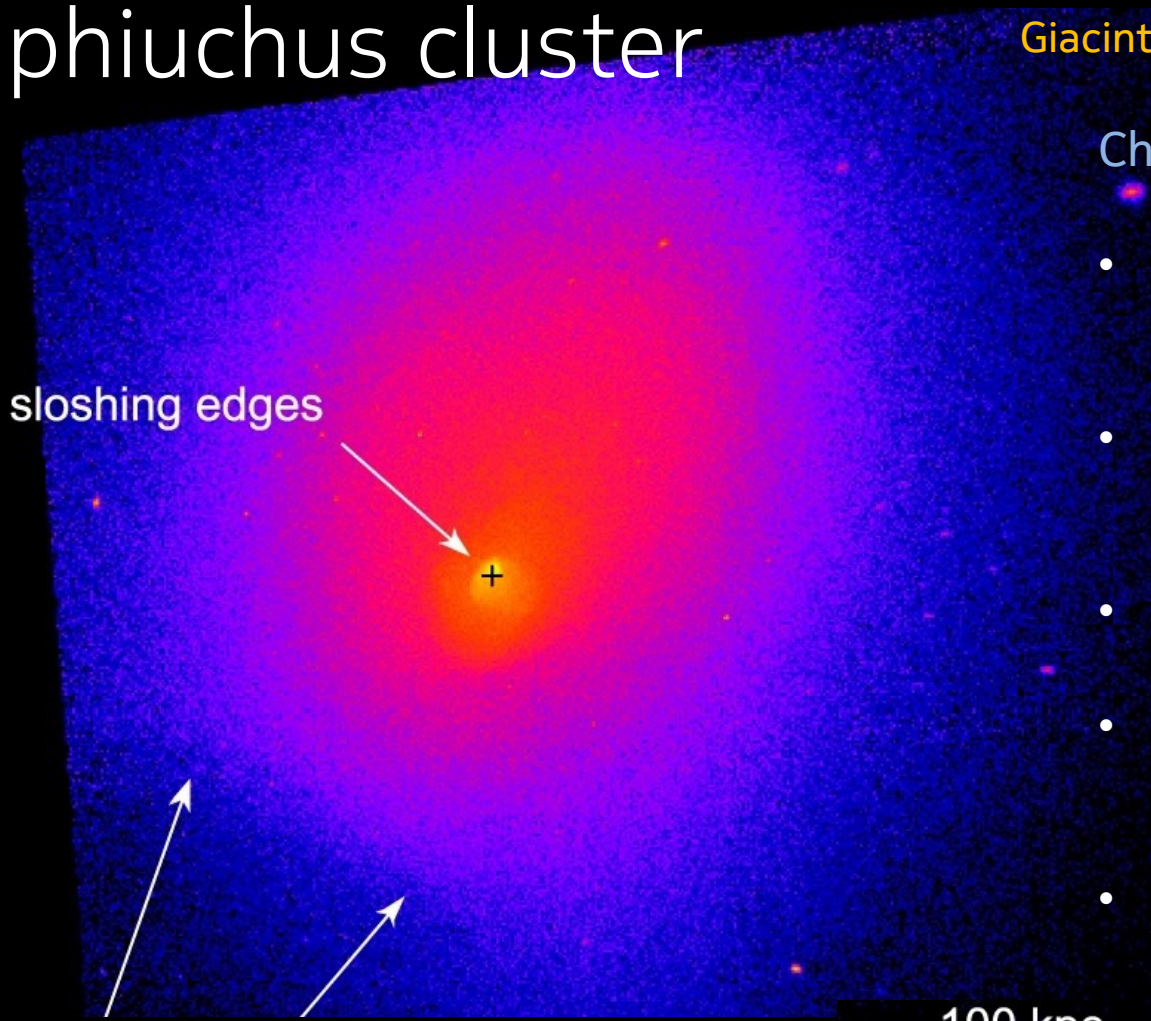
2. The most interesting NASA X-ray Probe concept

Maxim Markevitch, NASA GSFC

2022 August 17

Ophiuchus cluster

Giacintucci et al. 2020, 2022 in prep.

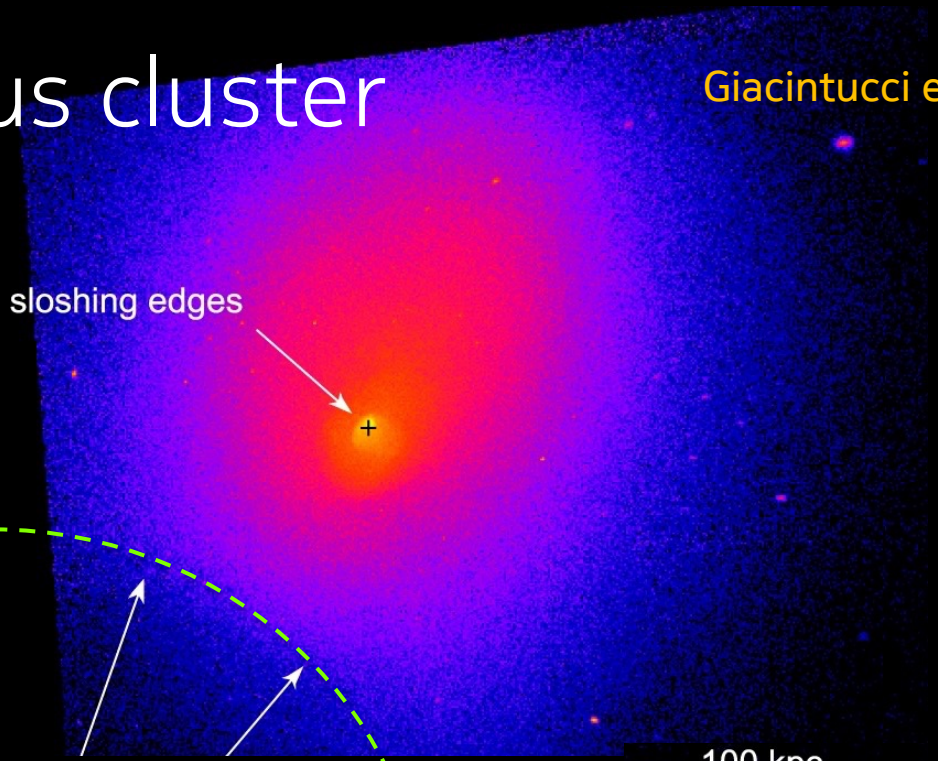


Chandra X-ray image

- Massive cluster (T=10 keV)
- steep temperature decline at center
- multiple sloshing edges
- gas peak offset from BCG (one of rare cases)
- AGN very faint (deprived of fuel by sloshing)

Ophiuchus cluster

Giacintucci et al. 2020, 2022 in prep.



concave edge (Werner 16)

- Edge of a giant cavity?

Ophiuchus cluster

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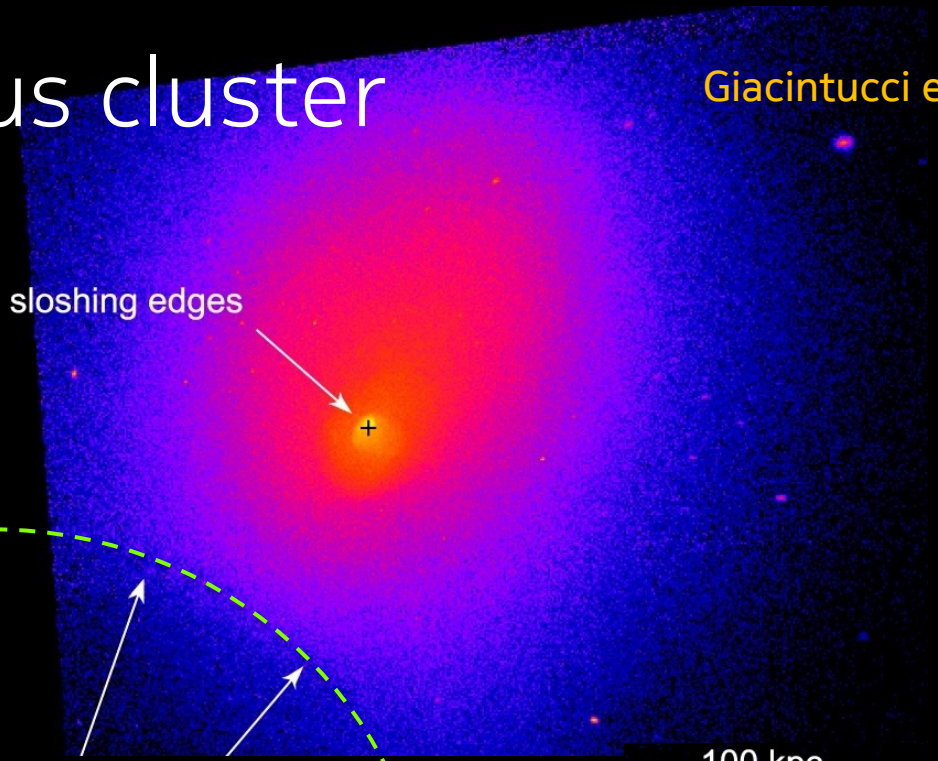
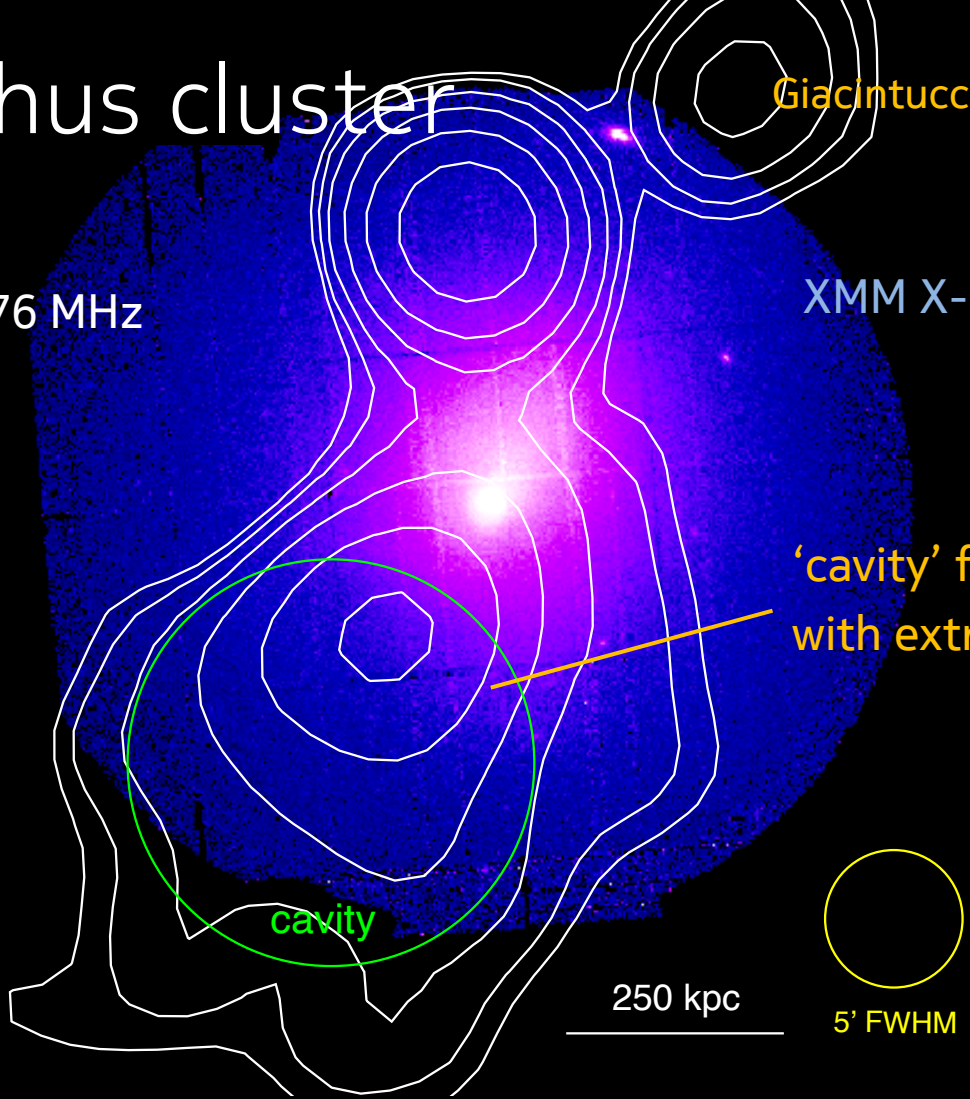


- Edge of a giant cavity?
- $pV \sim 5 \times 10^{61}$ erg — implausible: almost order of mag. greater than the biggest known AGN cavity (MS0735+74, McNamara 05)

Ophiuchus cluster

Giacintucci et al. 2020, 2022 in prep.

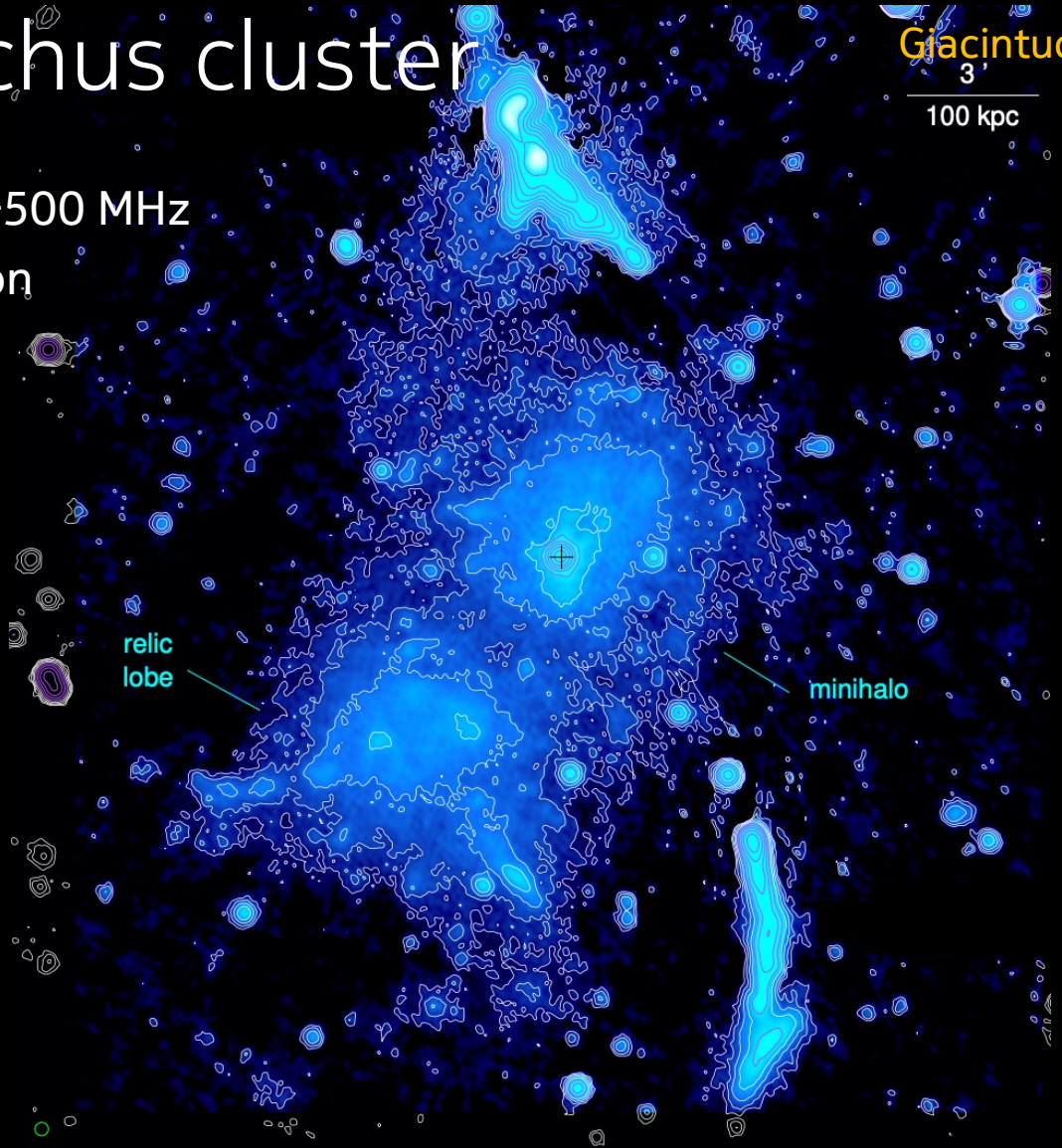


Ophiuchus cluster

Giacintucci et al. 2022 in prep.

uGMRT 300–500 MHz

18” resolution



Ophiuchus cluster

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uGMRT 300–500 MHz

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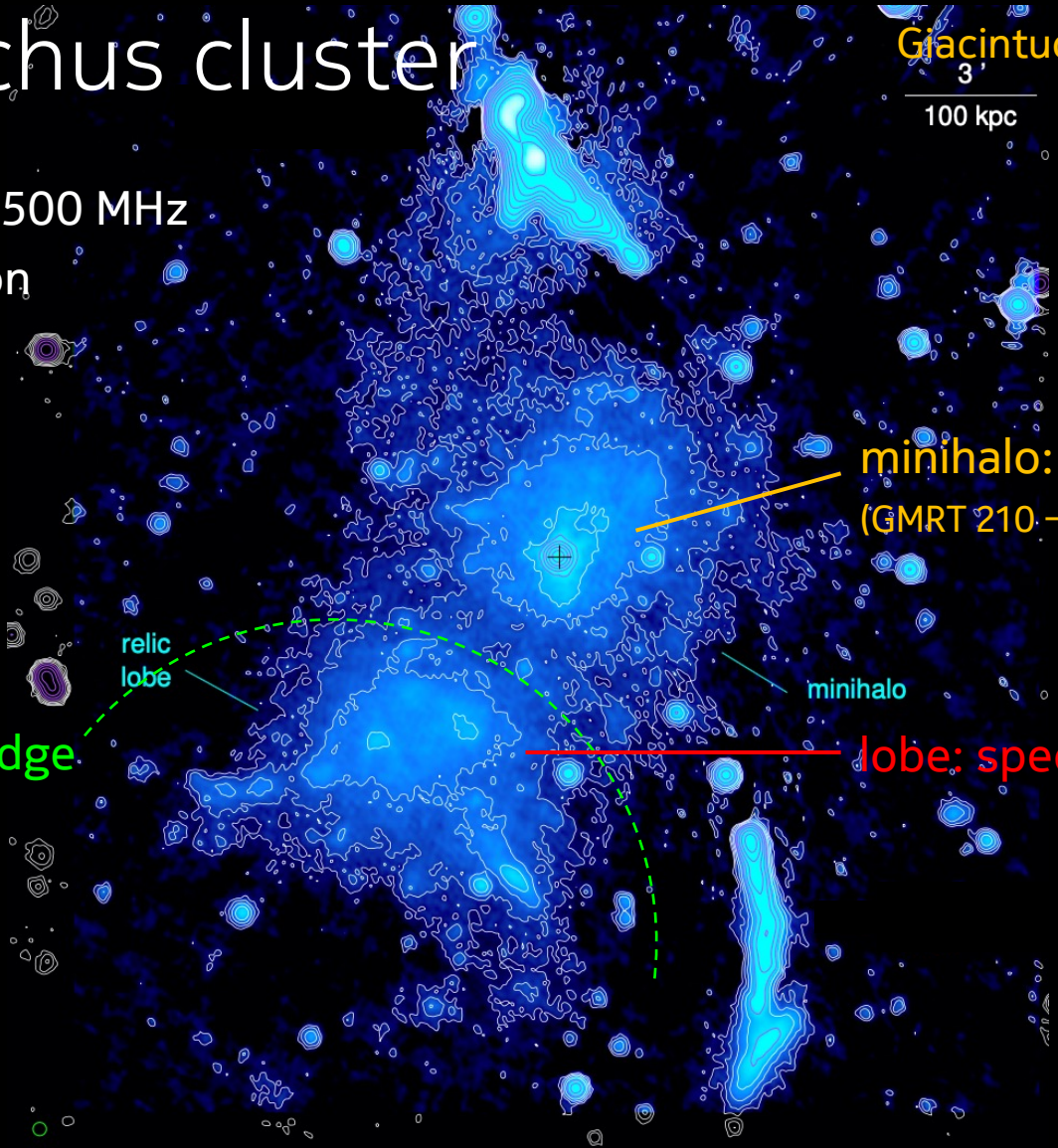


minihalo: spectral index −1

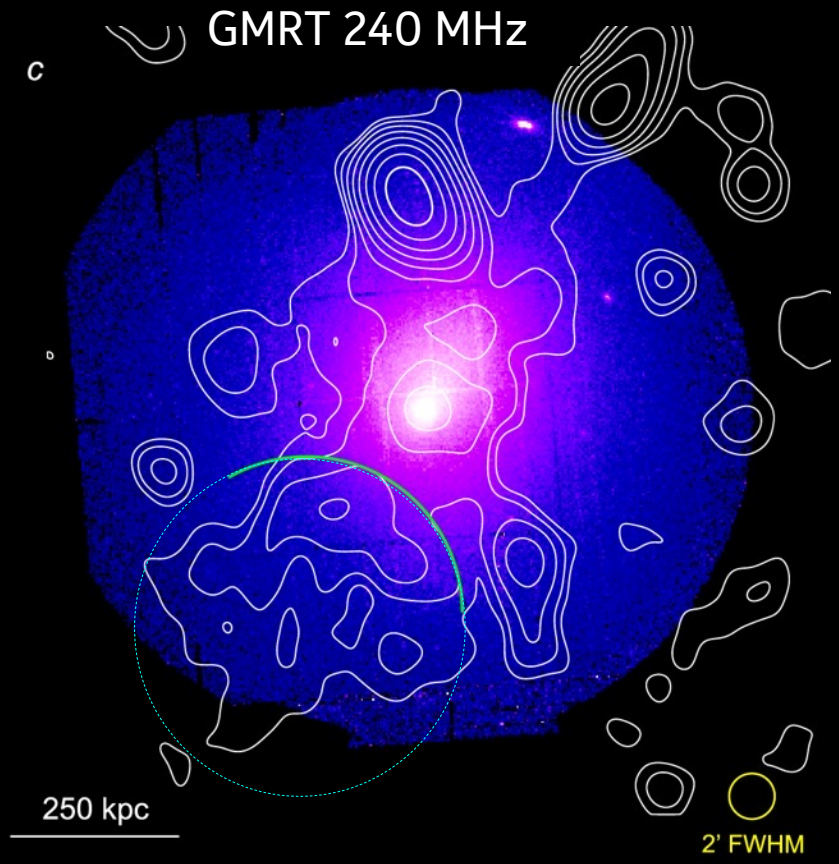
(GMRT 210 –400 MHz)

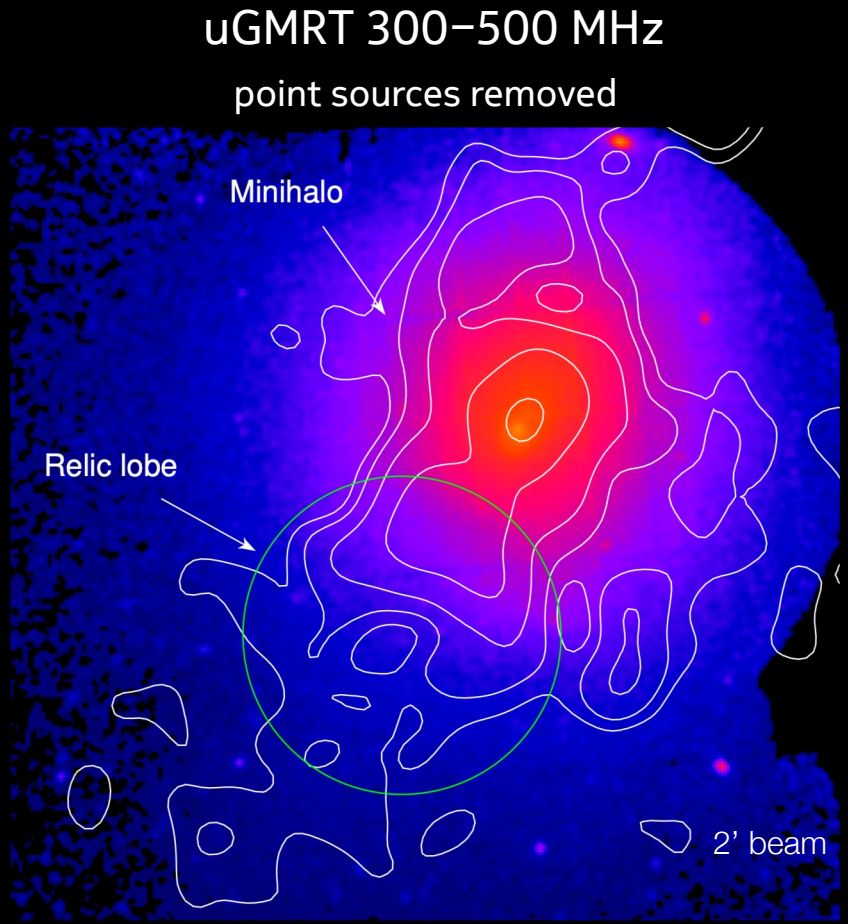
X-ray edge

lobe: spectral index −2.5

Ophiuchus cluster

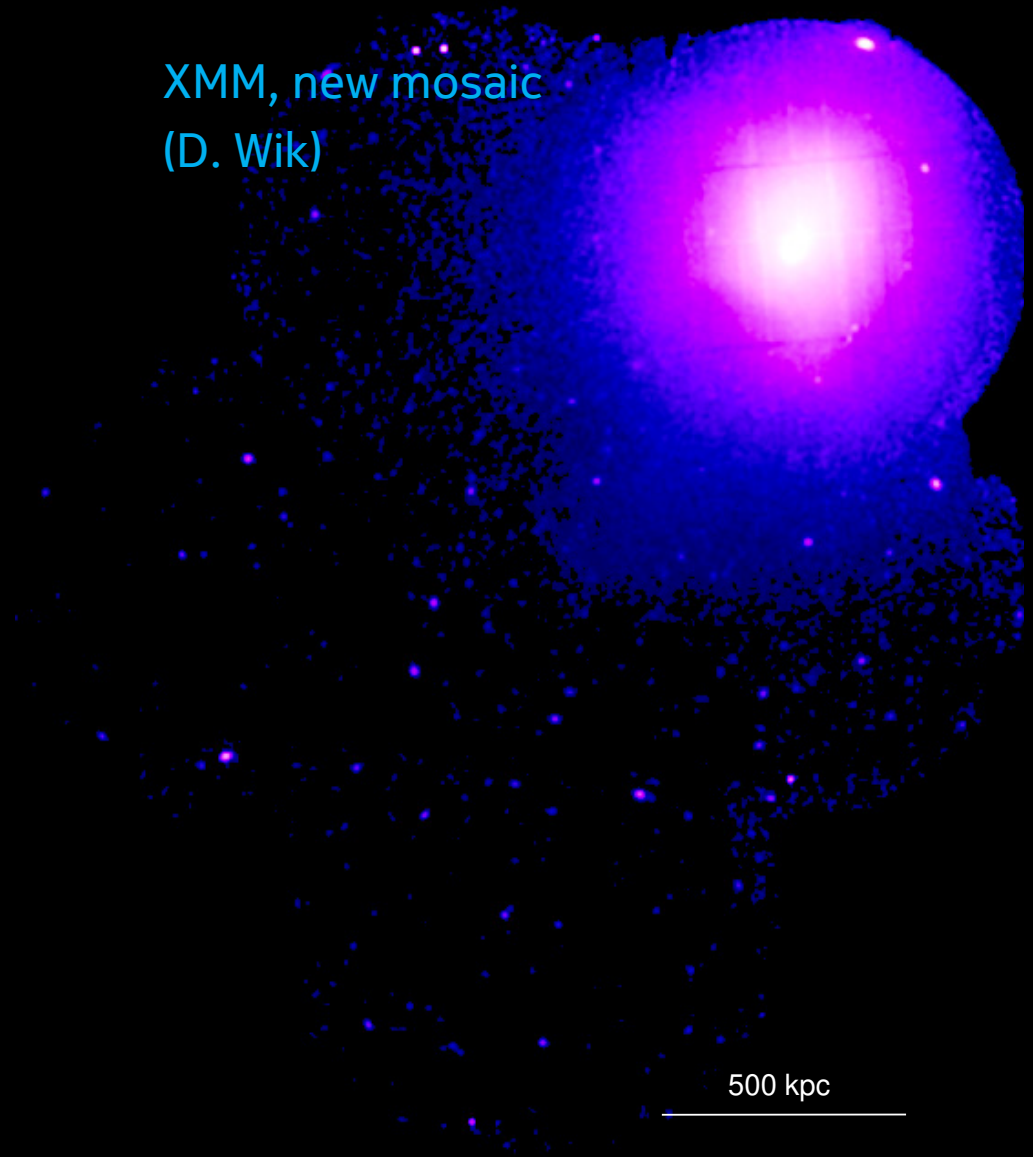
Giacintucci et al. 2020, 2022 in prep.



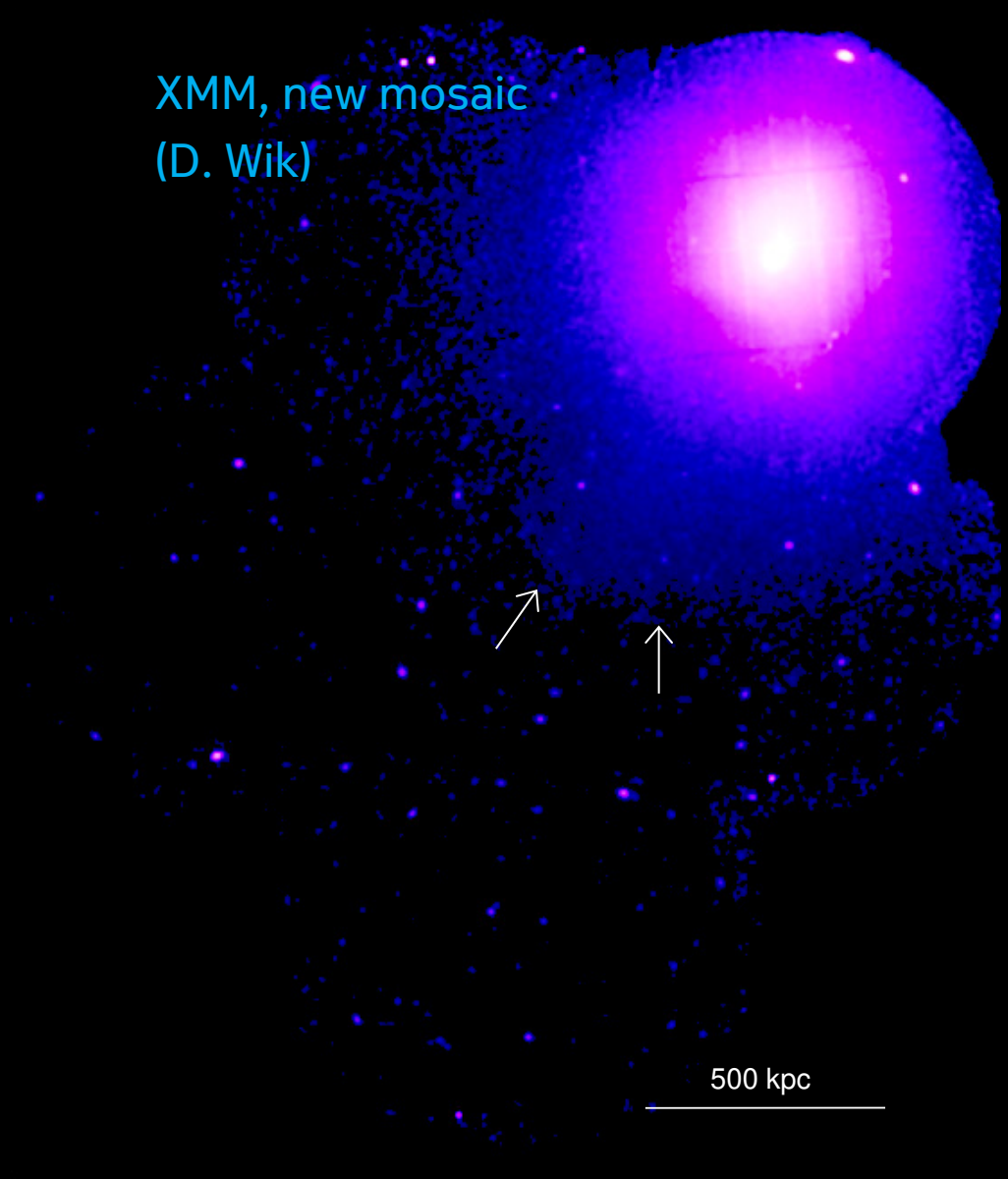


What about the rest of the X-ray “cavity”?

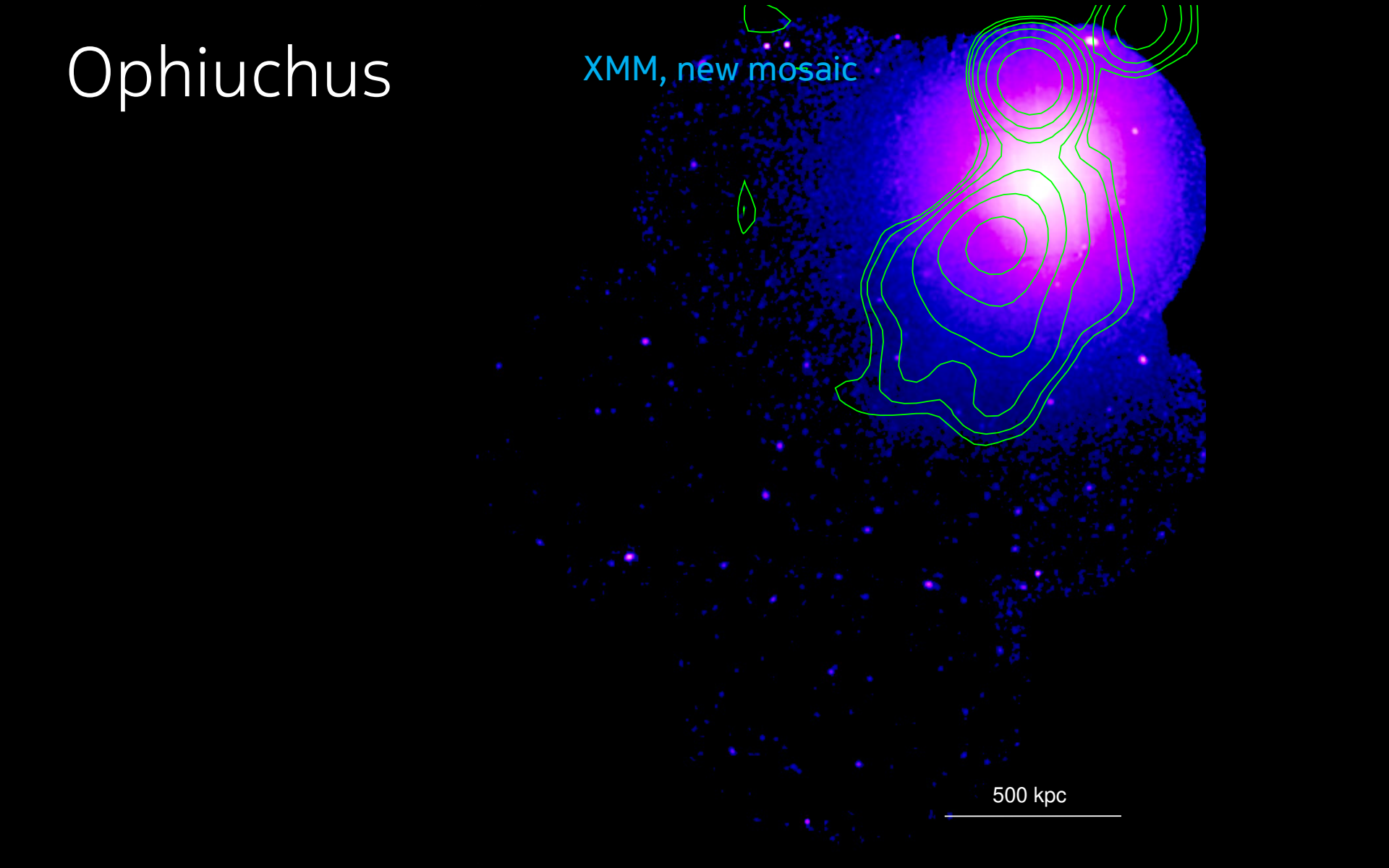
Ophiuchus



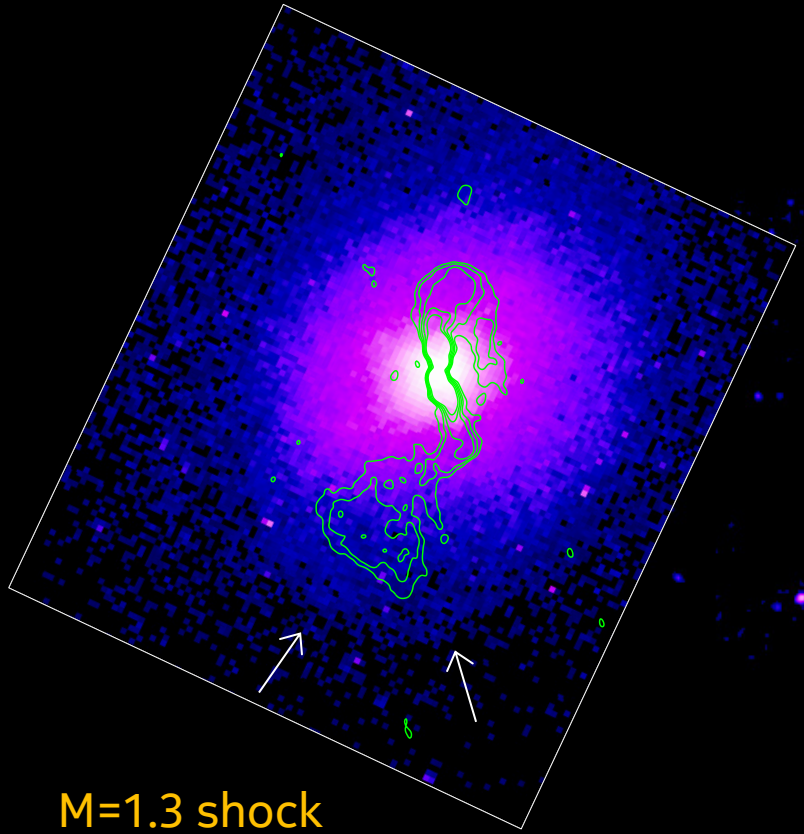
Ophiuchus



Ophiuchus



Hydra A



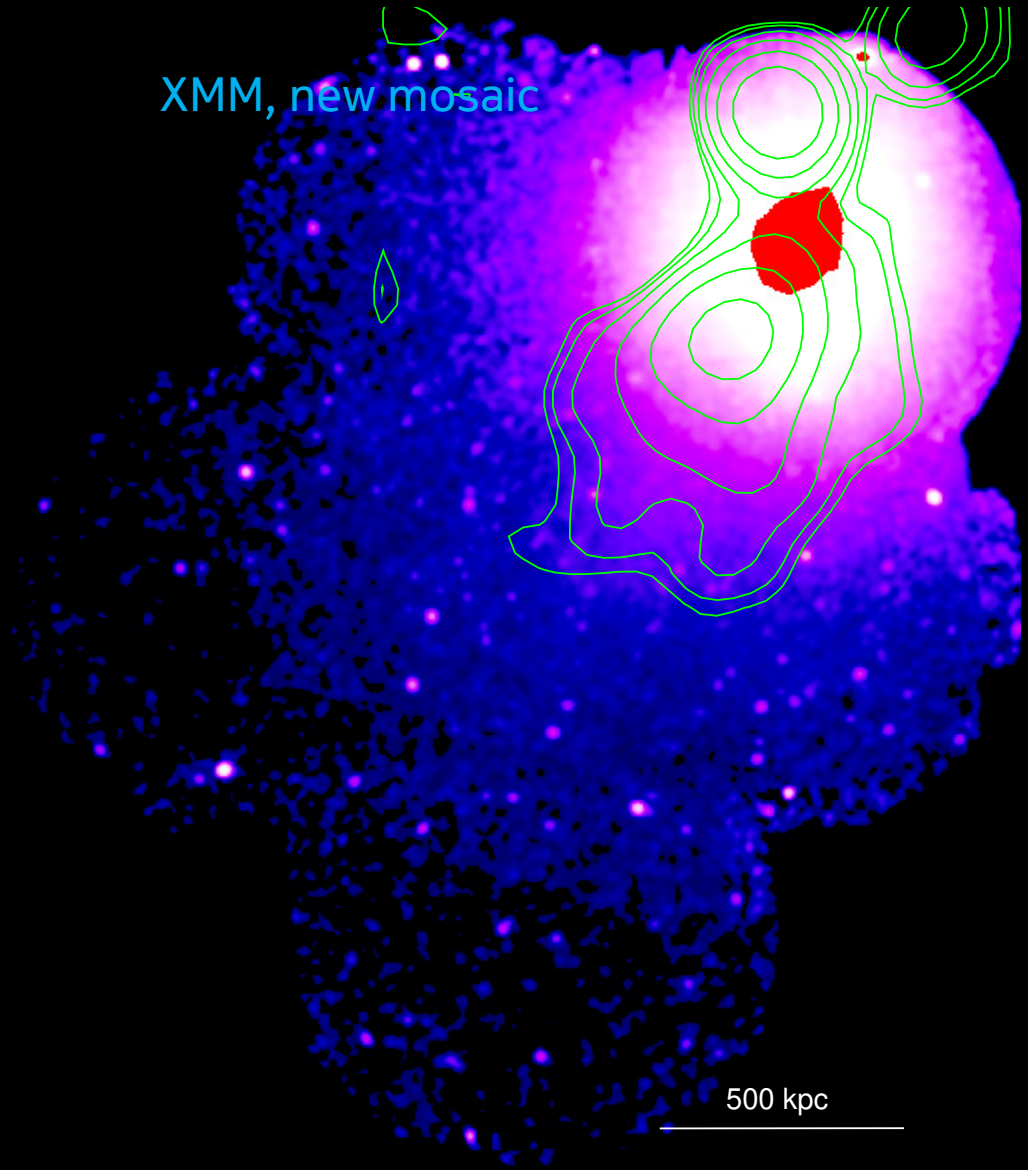
M=1.3 shock

(Nulsen 05, Simionescu 09)

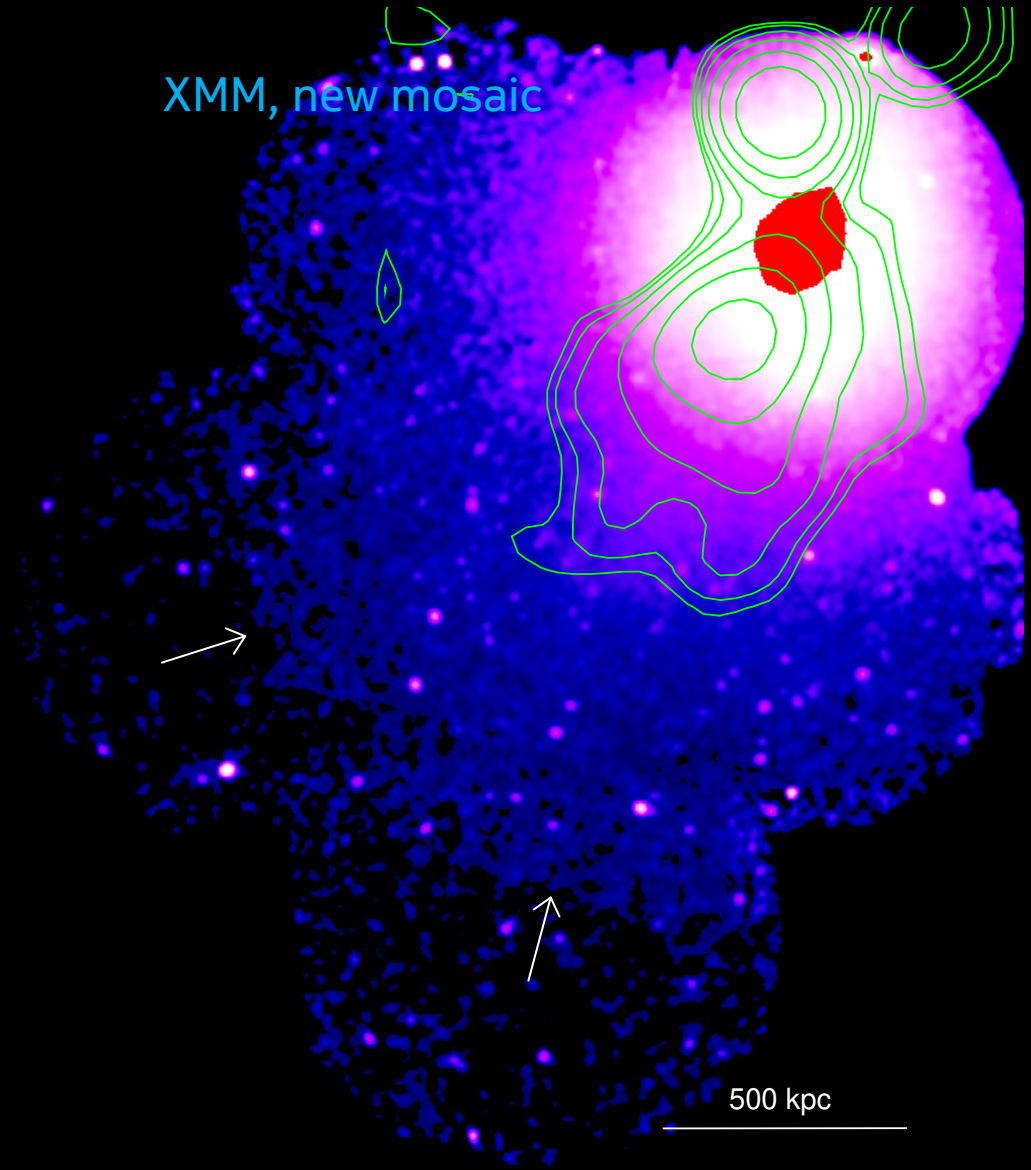
XMM, new mosaic

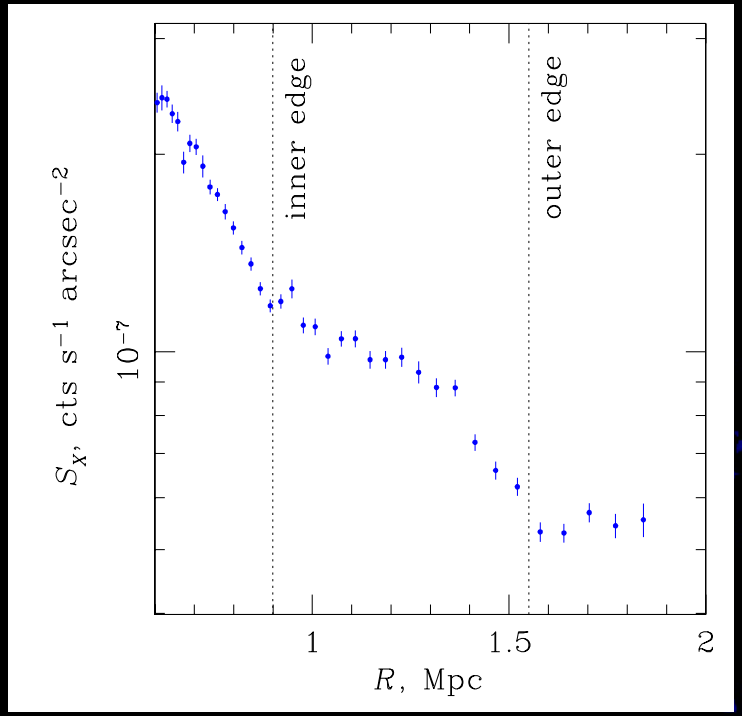
500 kpc

Ophiuchus



Ophiuchus





X-ray brightness profile

XMM, new mosaic

- inner edge: AGN bubble driven weak shock?
- outer edge: another giant sloshing front at r=1.5 Mpc? driven by bubble or by independent merger

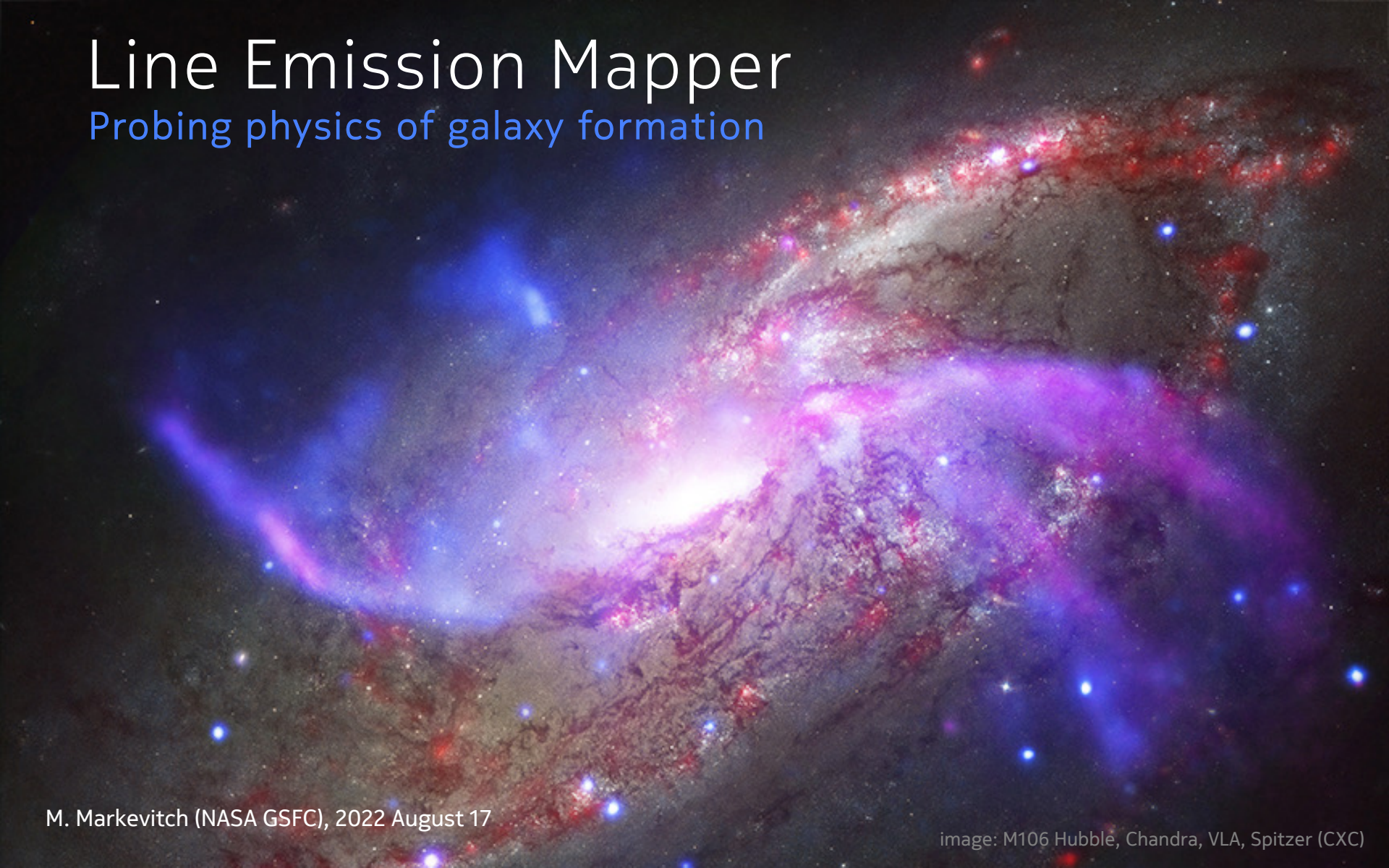
500 kpc

Conclusions

- The dinosaur AGN explosion in Ophuichus is real
  - the most energetic known explosion since Big Bang,
    pV ~ 5×10^{61} erg, d=0.5 Mpc cavity – large outlier among AGN cavities
  - disturbed the whole massive cluster – but didn't destroy its cool core! (all energy deposited outside the core?)
    - possibly set off cluster-wide sloshing
- companion lobe probably faded or was completely disrupted
- If search at sufficiently low radio frequencies, may find more dinosaurs (some candidates already)
- with time, this lobe will be swept to outskirts by sloshing and form relic-like cloud to be reaccelerated, or one of LOFAR ultra-steep sources

Line Emission Mapper

Probing physics of galaxy formation



M. Markevitch (NASA GSFC), 2022 August 17

image: M106 Hubble, Chandra, VLA, Spitzer (CXC)

Line Emission Mapper (Probe, 2032)

Grazing-incidence mirror

1600 cm^2 effective at E=0.5 keV

0.2 –2 keV band

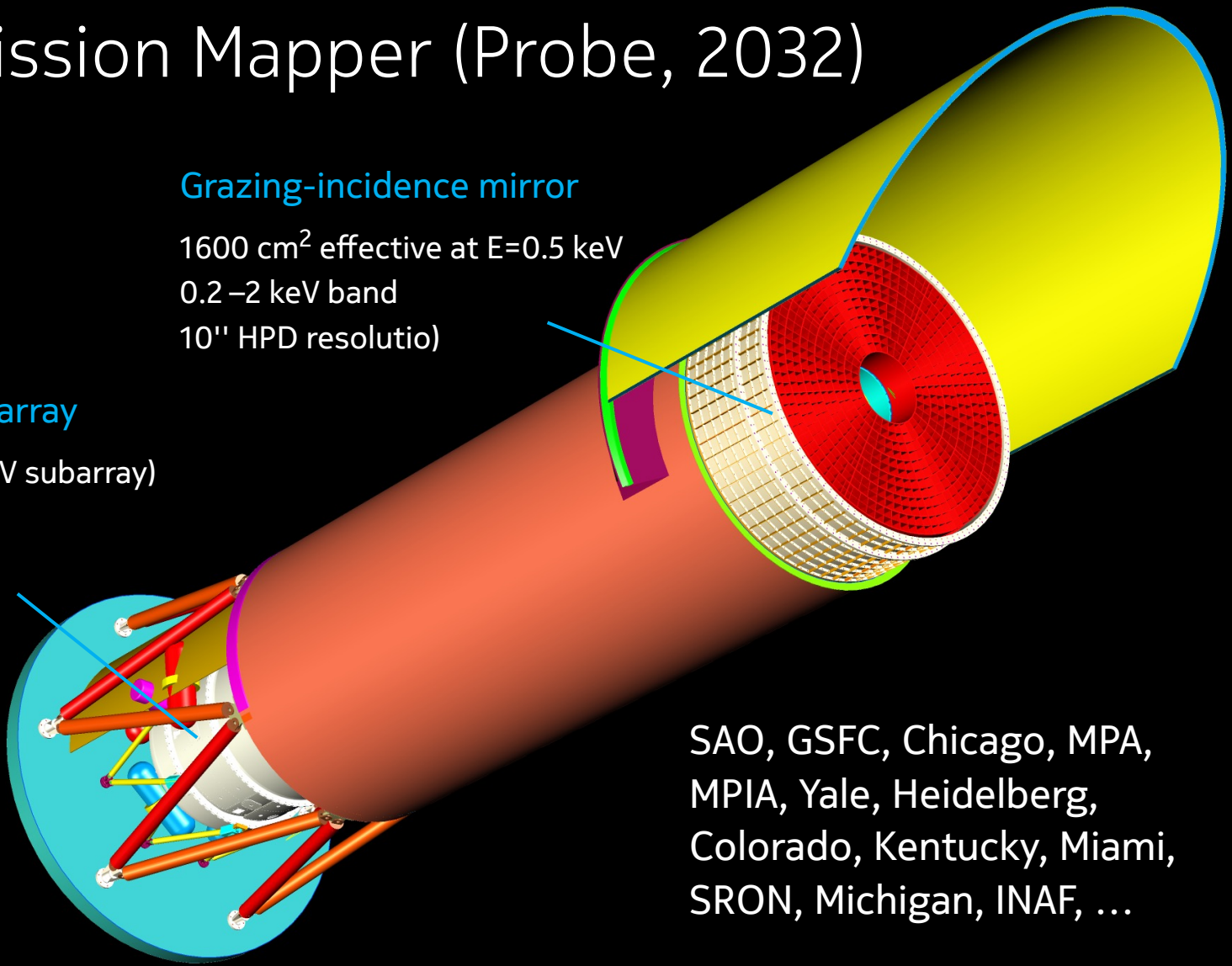
10'' HPD resolutio)

TES calorimeter array

2 eV resolution (1 eV subarray)

30'×30' field

118×118 15" pixels



SAO, GSFC, Chicago, MPA, MPIA, Yale, Heidelberg, Colorado, Kentucky, Miami, SRON, Michigan, INAF, …

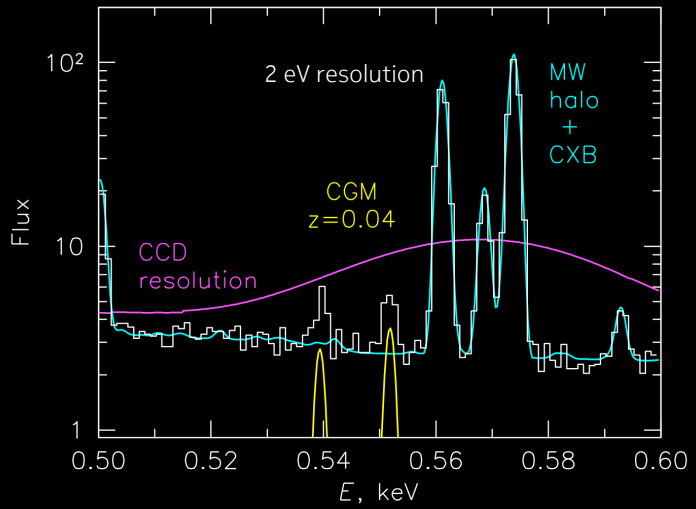
LEM vs. future spectroscopy missions

	LEM	XRISM	Athena	Lynx†	HUBS†
Energy band, keV	0.2–2	0.4–15	0.2–12	0.2–7	0.2–2
Effective area, cm^2					
0.5 keV	1600	50	6000	14000	500
6 keV	0	300	2000	...	0
Field of view	30'	3'	5'	5'	60'
Grasp* at 0.5 keV	1.4	<0.001	0.12	0.35	1.8
Angular resolution	15"	1'	5"	1"	1'
Spectral resolution	1-2 eV	5 eV	2.5 eV	3 eV	1-2 eV
Detector array, pix	118×118**	6×6	50×50**	300×300	60×60

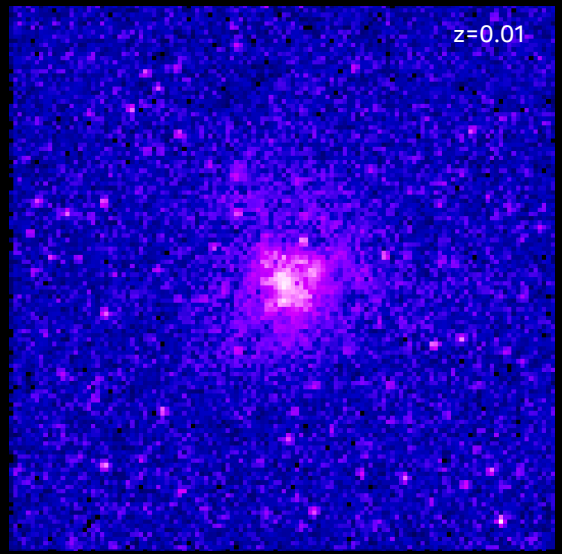
* grasp = effective area × field of view, 10^6 cm^2 $arcmin^2$ ** equivalent square † future concepts

v2022-5-30

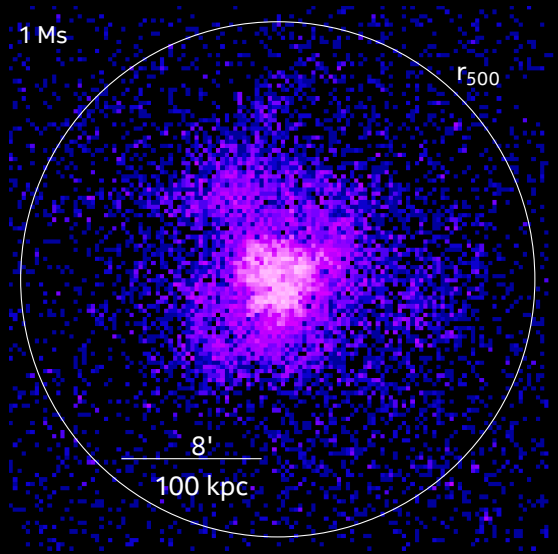
Uncovering the Circumgalactic Halos



simulated galaxy: CCD image at E=0.5 keV



LEM image in OVII line, 2 eV resolution



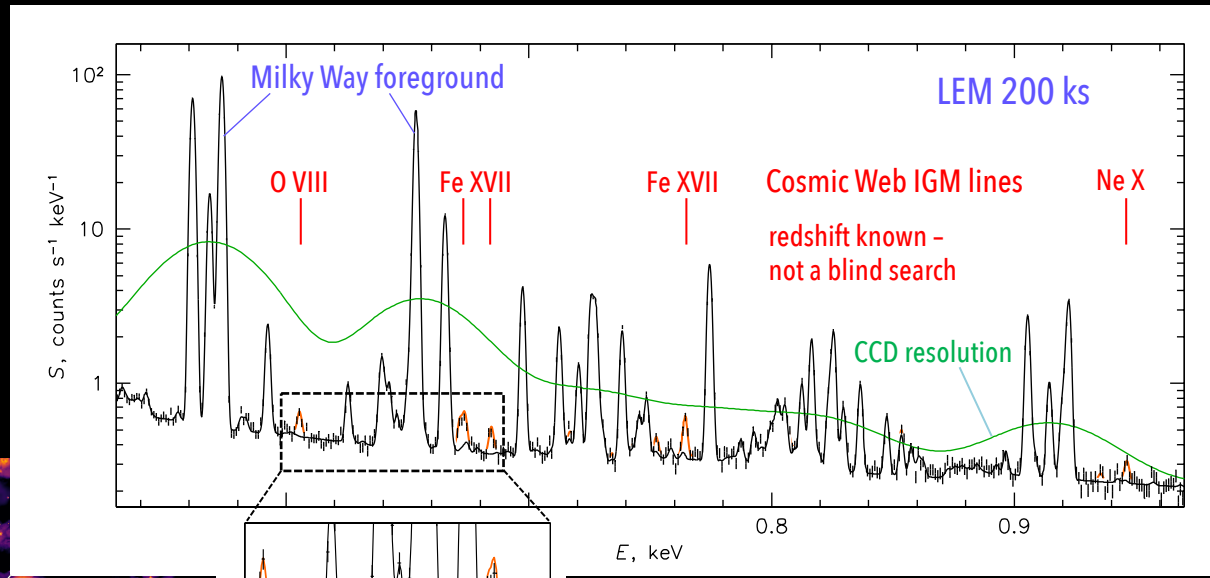
- CGM emission lines are located next to much brighter Milky Way foreground lines – cannot be separated with CCD resolution

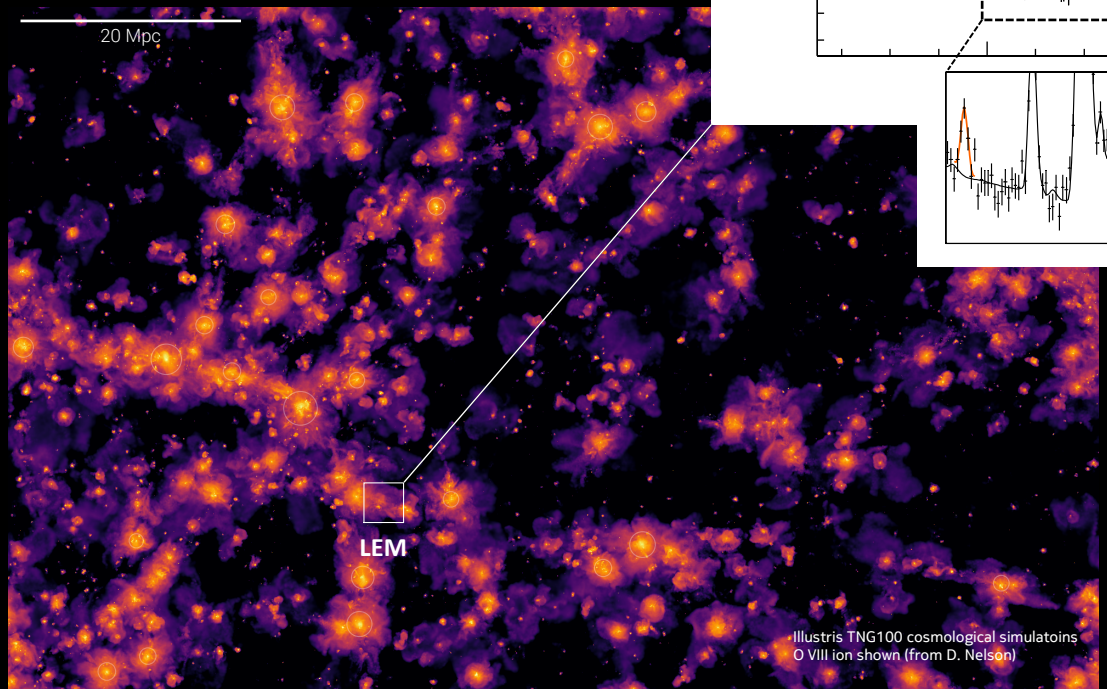
Milky Way foreground dominates

LEM resolves foreground, unveils CGM

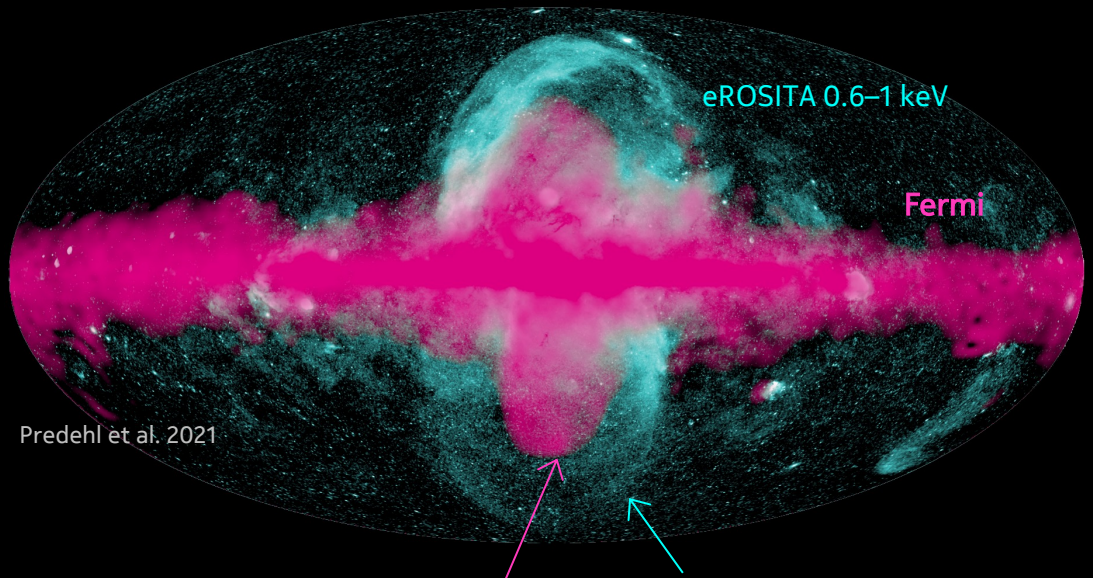
- LEM's 2 eV resolution allows to isolate signal from foreground, unveil the very faint CGM halo
- LEM's large grasp allows to map the entire halo of a nearby well-resolved galaxy in a single (long but feasible) ~1 Ms exposure
- This cannot be done with a dispersive (grating) spectrometer – mapping diffuse emission requires an imaging microcalorimeter

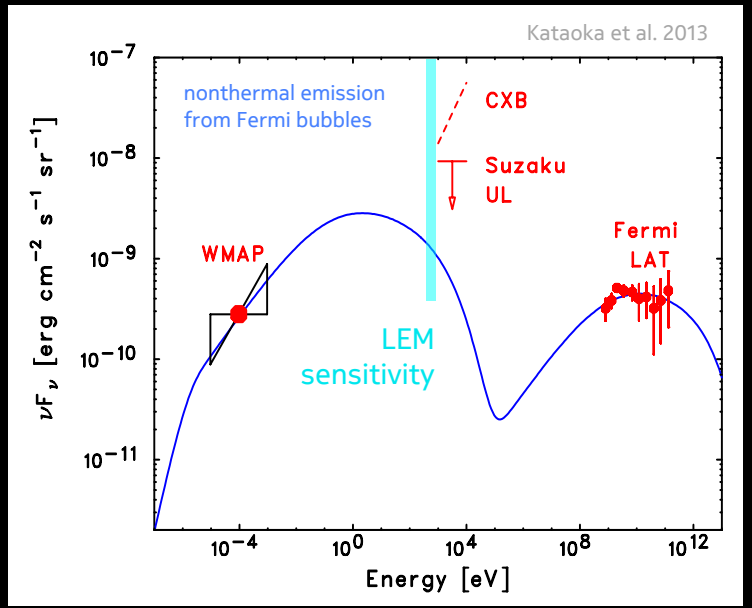
Detecting metals in Cosmic Web filaments





LEM will do a shallow all-sky survey

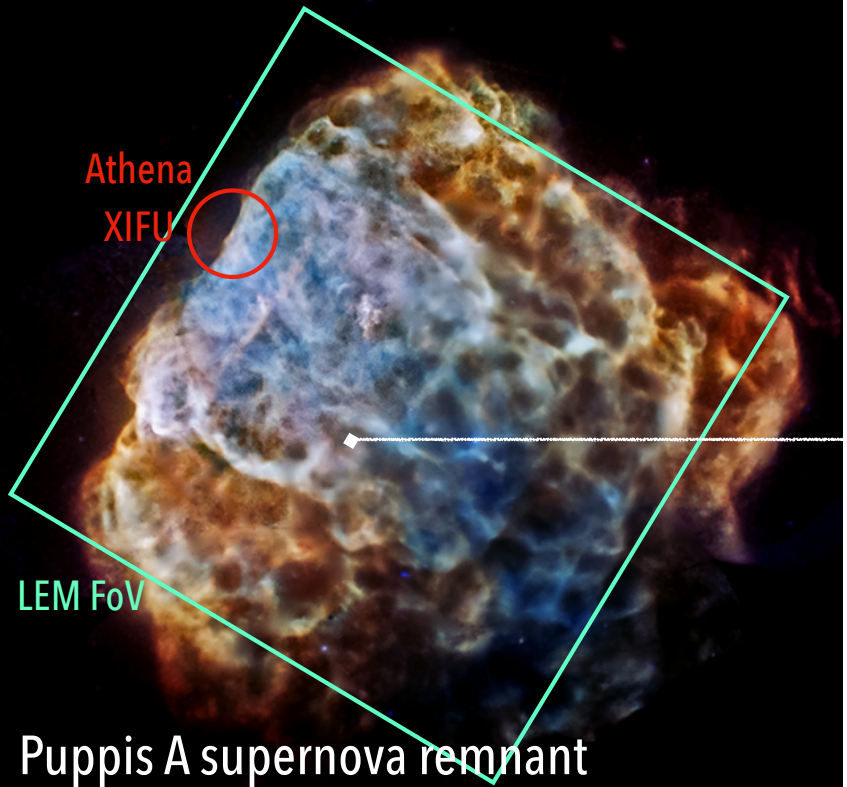


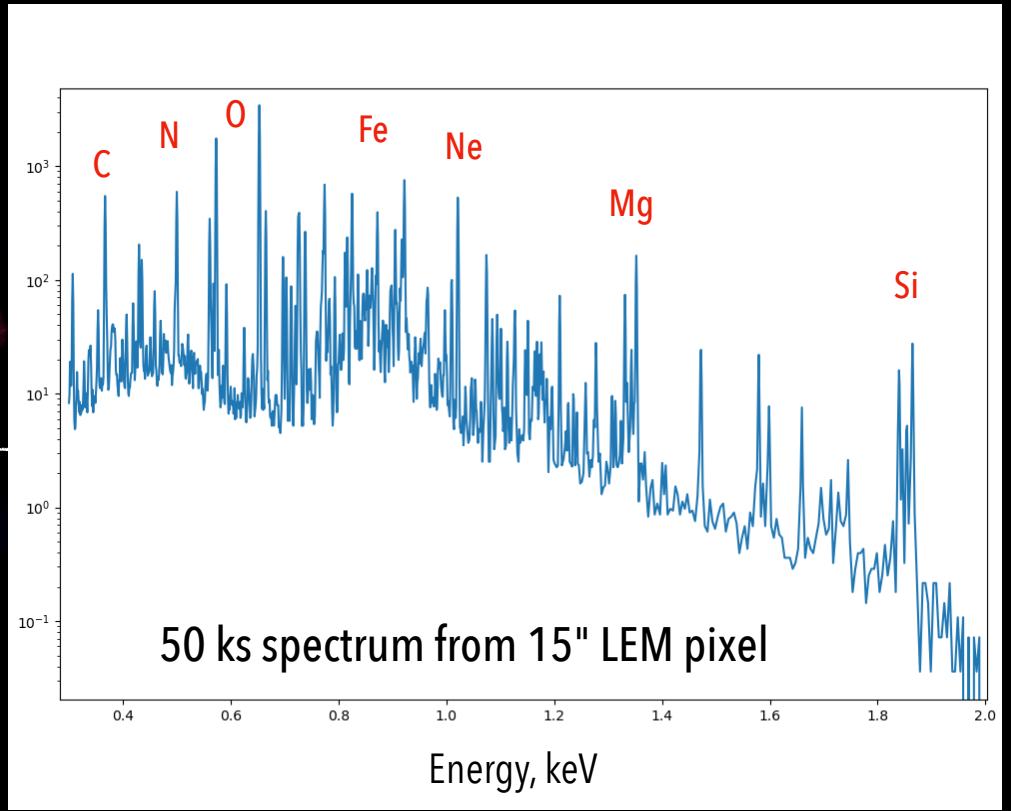


Map Milky Way CGM, Fermi and eROSITA Bubbles

- constrain or (with luck) detect **nonthermal emission** from Fermi bubbles by resolving line-dominated diffuse foreground

Every 15” pixel in 118×118 (30’x30’) array is a calorimeter





Science ideas welcome (go wild)