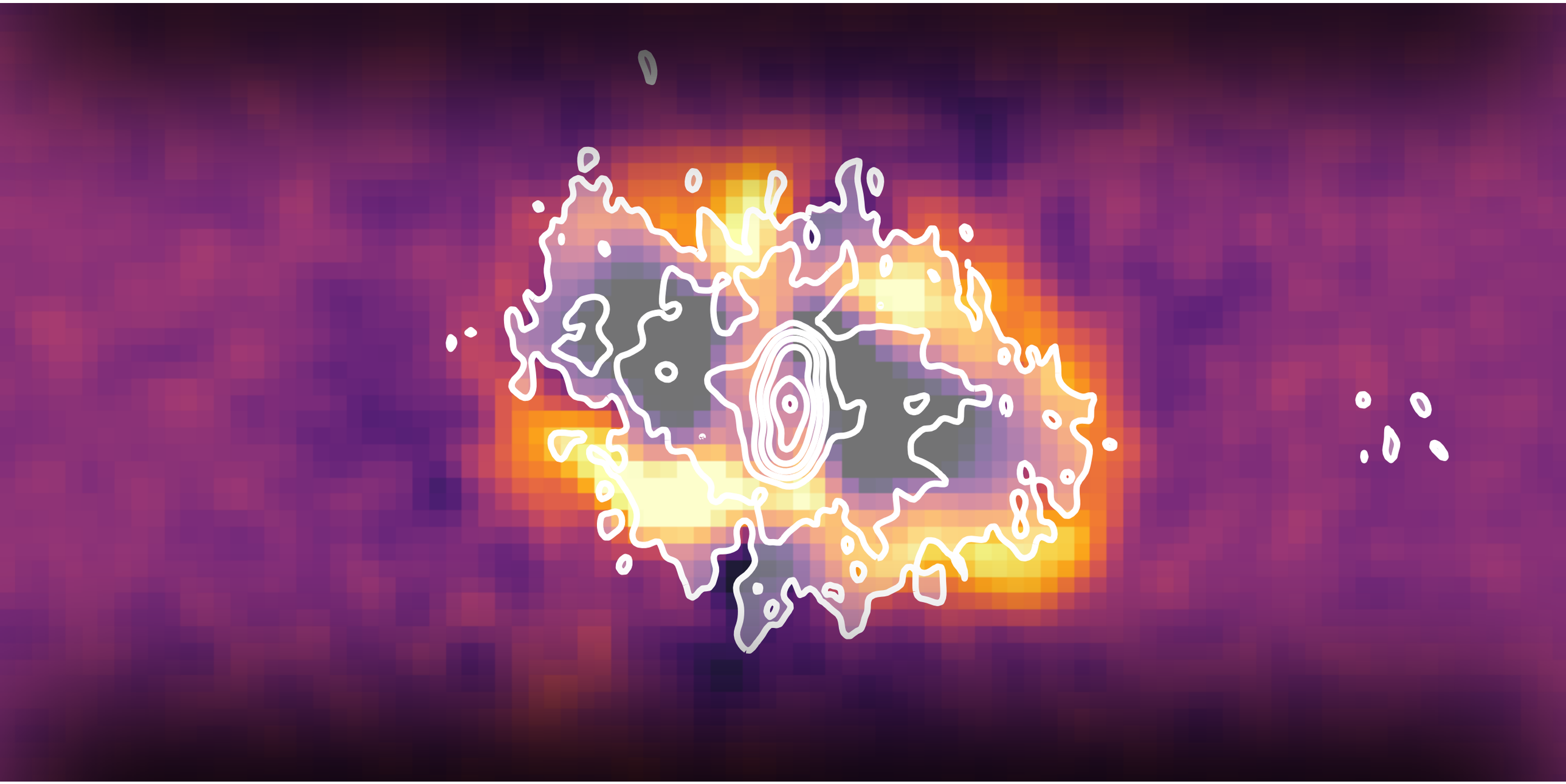
The strong cool core cluster RBS 797: a *Chandra* window on extreme AGN feedback



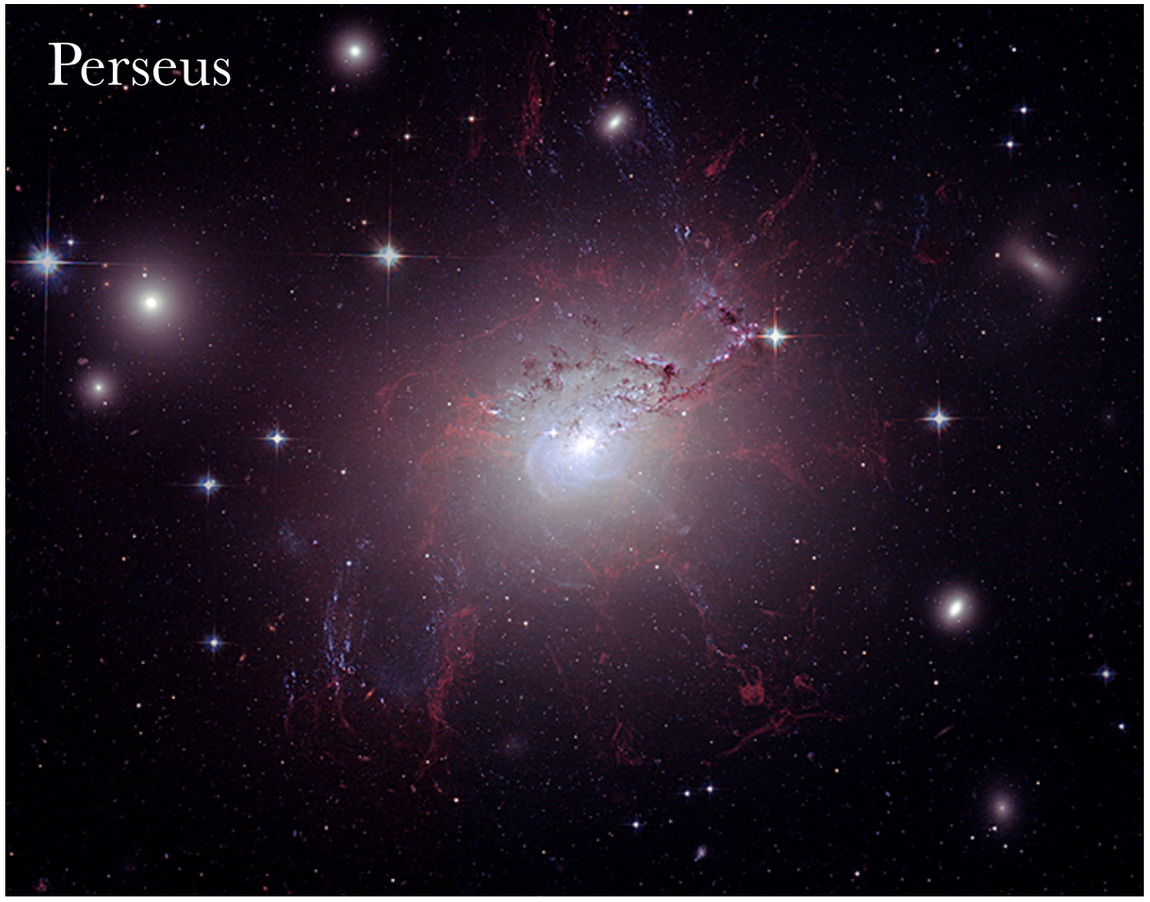
FRANCESCO UBERTOSI

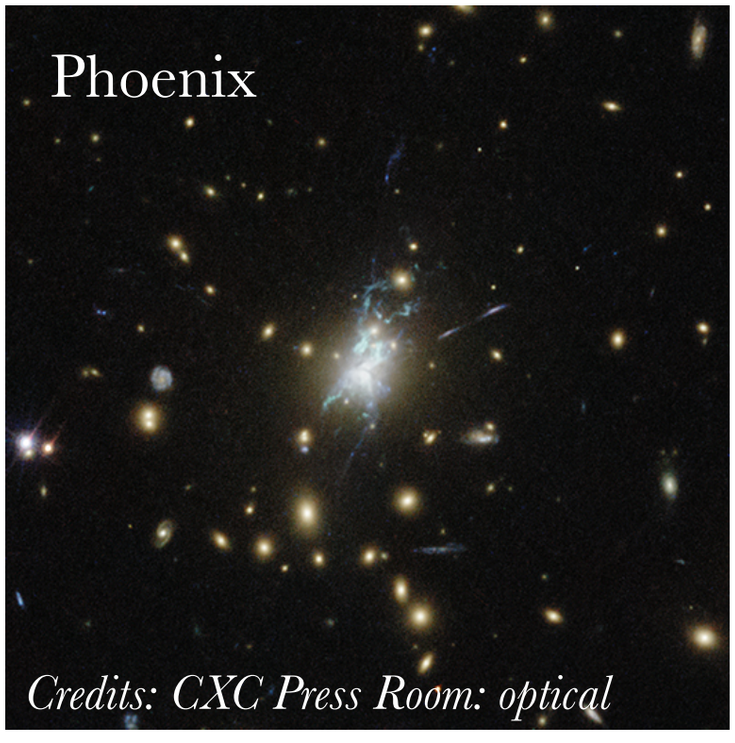
Post-doc researcher @ University of Bologna

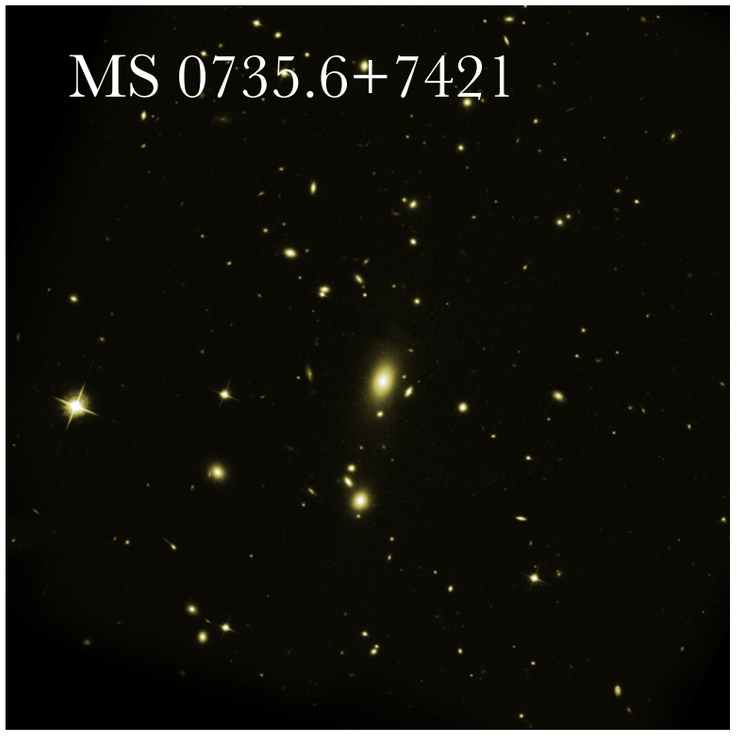
with Myriam Gitti, Fabrizio Brighenti +

25 Years of Chandra science - francesco.ubertosi2@unibo.it

Scientific Background and Motivation







The core of relaxed clusters: a perfect stage for a dramatic **galaxy - BH - hot halo** interplay

1. Brightest cluster galaxies (BCGs) $M_\star \sim 10^{11} - 10^{12}\ M_\odot$

(e.g., for reviews McNamara & Nulsen 2007, 2012; Gitti et al. 2012; Fabian et al. 2012; Eckert et al. 2021; Donahue & Voit 2022)

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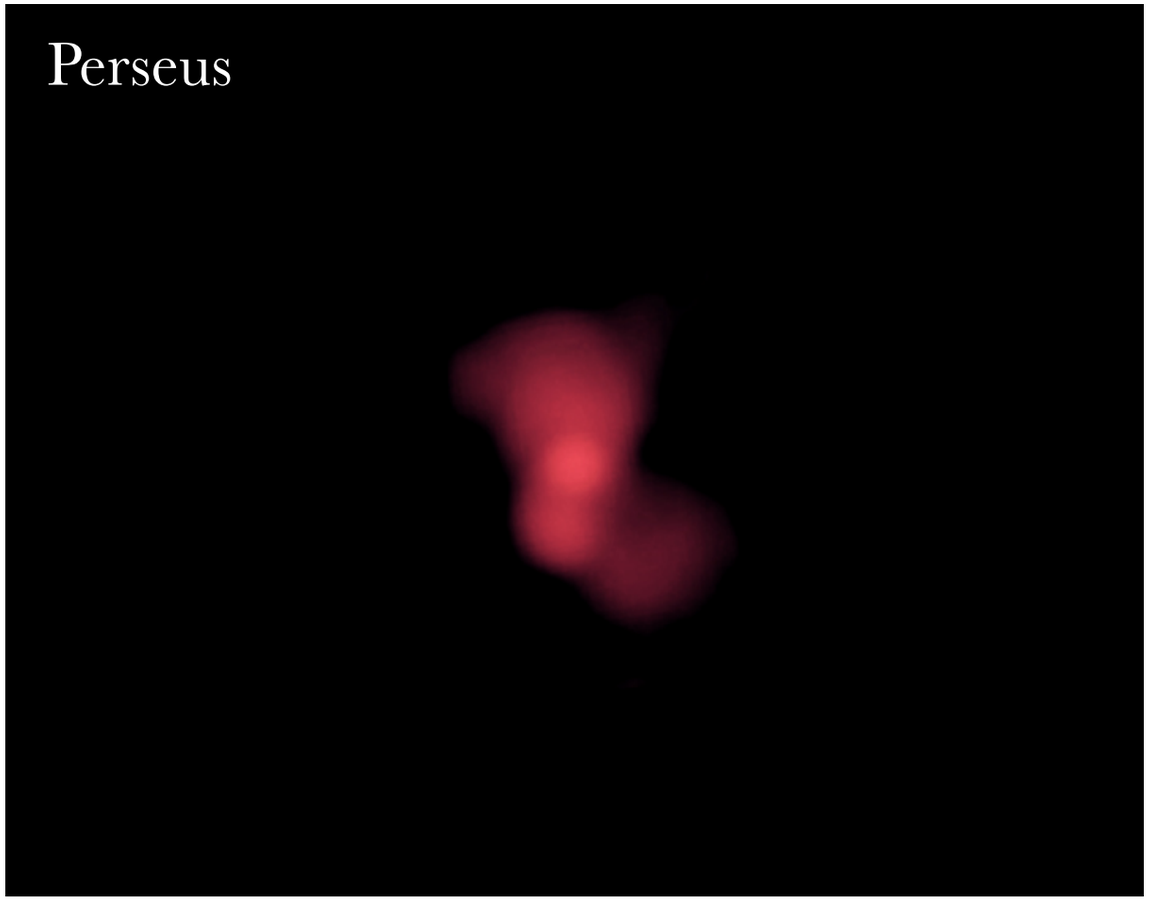

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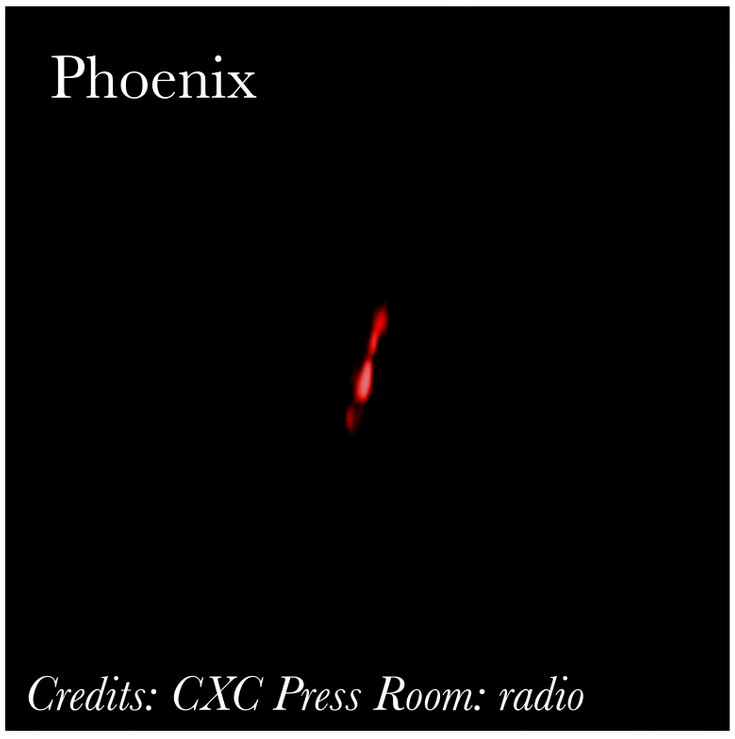

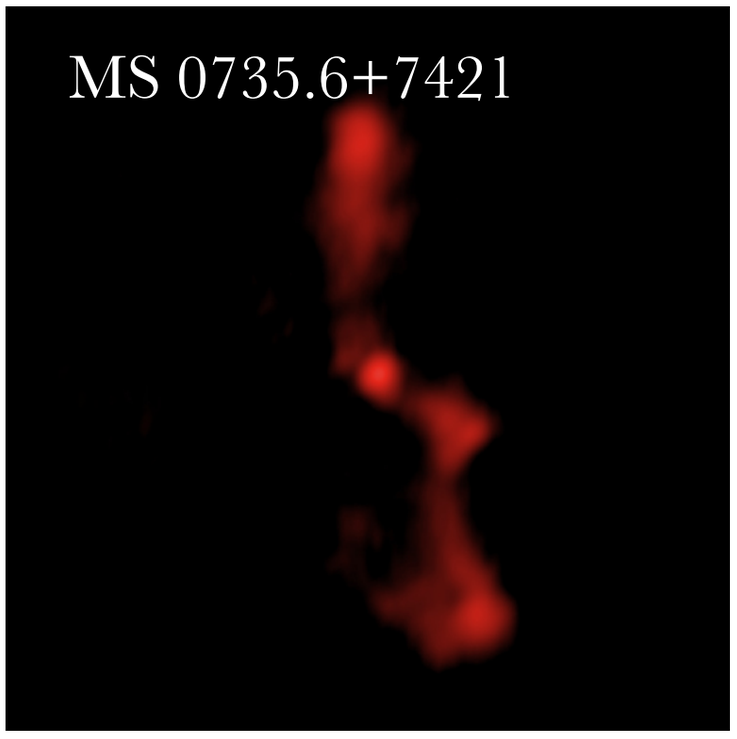

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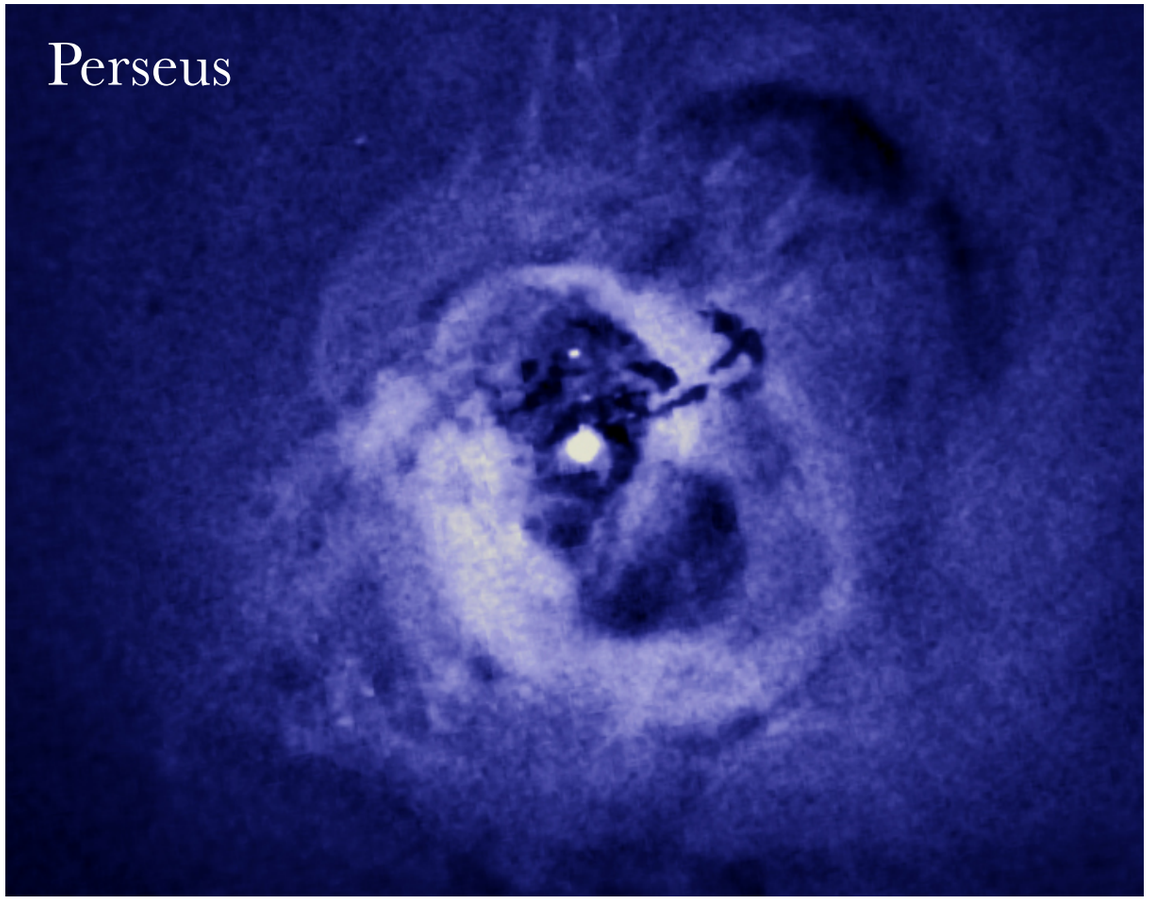
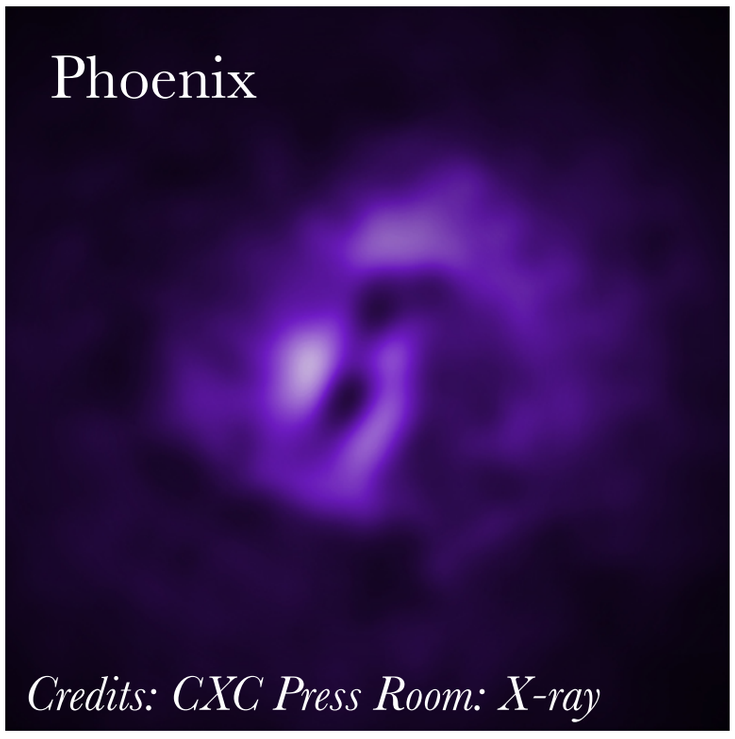


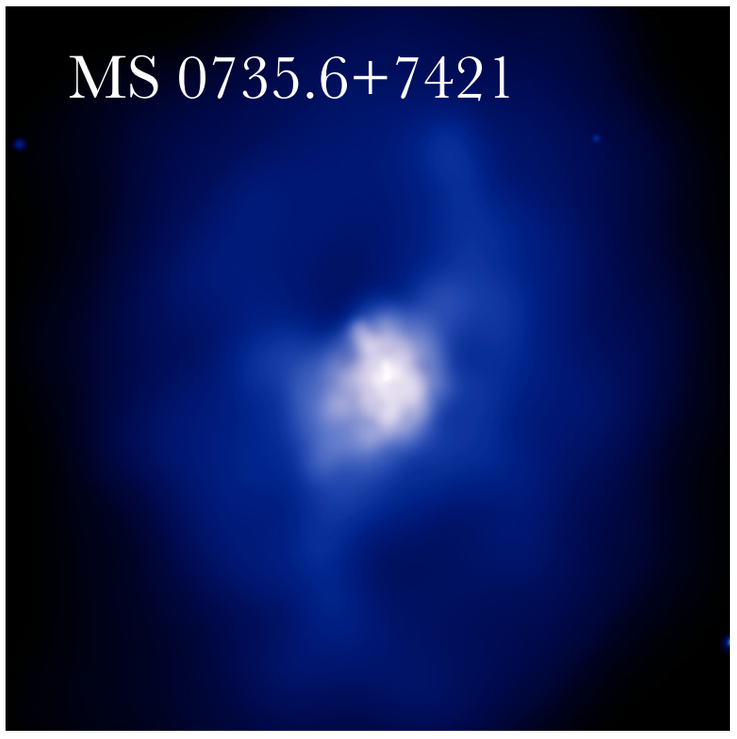
The core of relaxed clusters: a perfect stage for a dramatic **galaxy - BH - hot halo** interplay

1. Brightest cluster galaxies (BCGs) $M_\star \sim 10^{11} - 10^{12}\ M_\odot$

2. Supermassive BH accreting material and launching relativistic jets → AGN

3. The hot Intracluster Medium (ICM) retains the footprints of AGN activity





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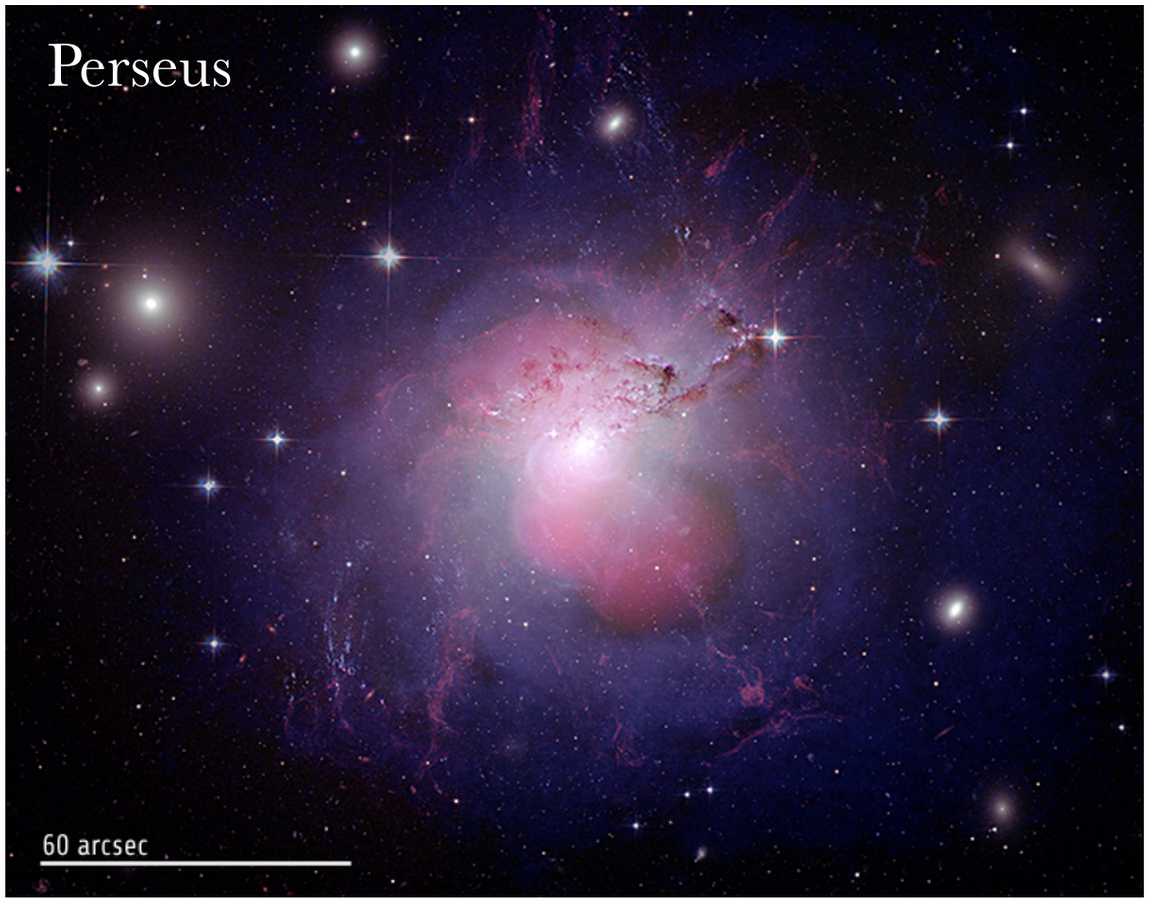


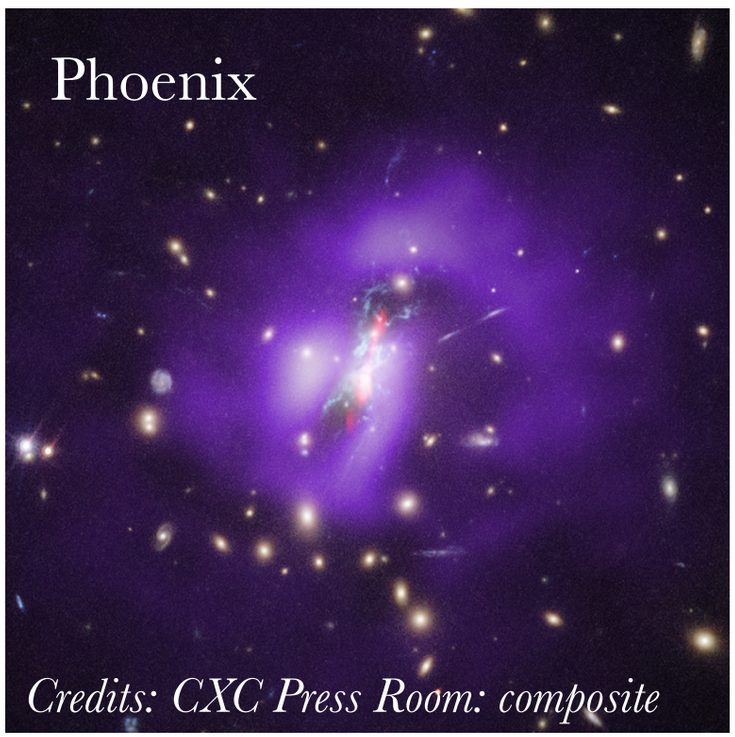
Piecing it all together…

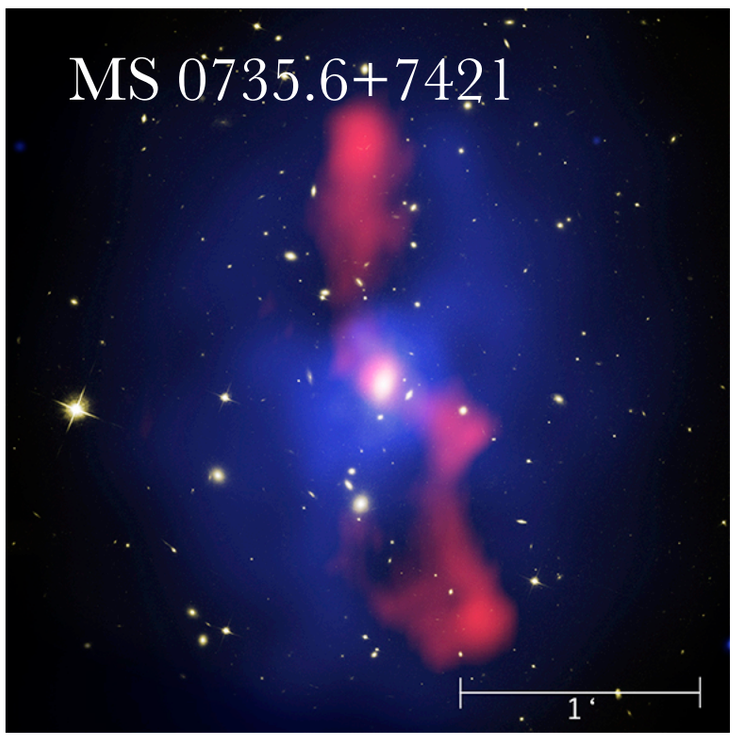
A self-regulated feeding & feedback loop

"X-ray cavities" correspond to the radio lobes of the central AGN

↓

Clearest signatures of jets injecting mechanical energy in the gas





+ nebulae of warm and cold gas surround the central AGN

↓

Residual ICM cooling fuels the activity of the SMBH

(e.g., for reviews McNamara & Nulsen 2007, 2012; Gitti et al. 2012; Fabian et al. 2012; Eckert et al. 2021; Donahue & Voit 2022)

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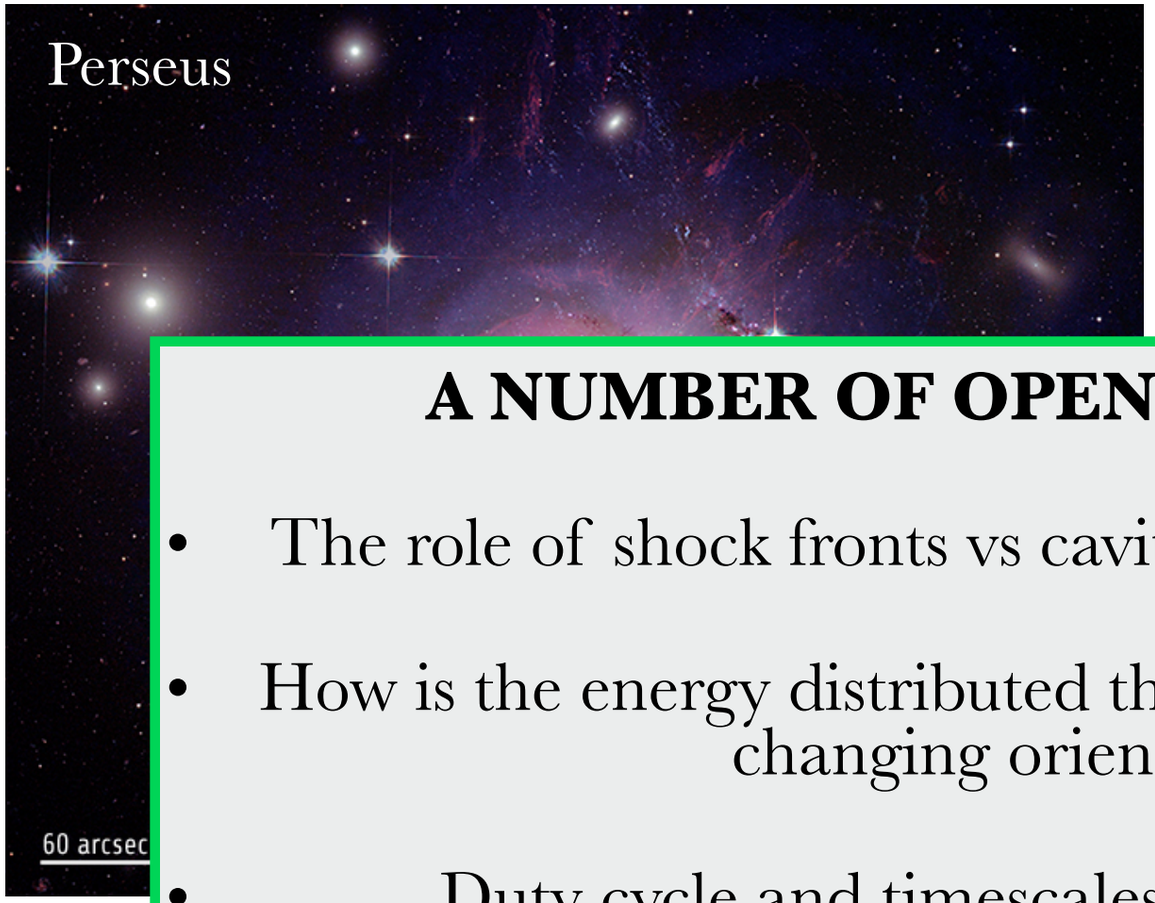


Piecing it all together…

A self-regulated feeding & feedback loop

A NUMBER OF OPEN QUESTIONS

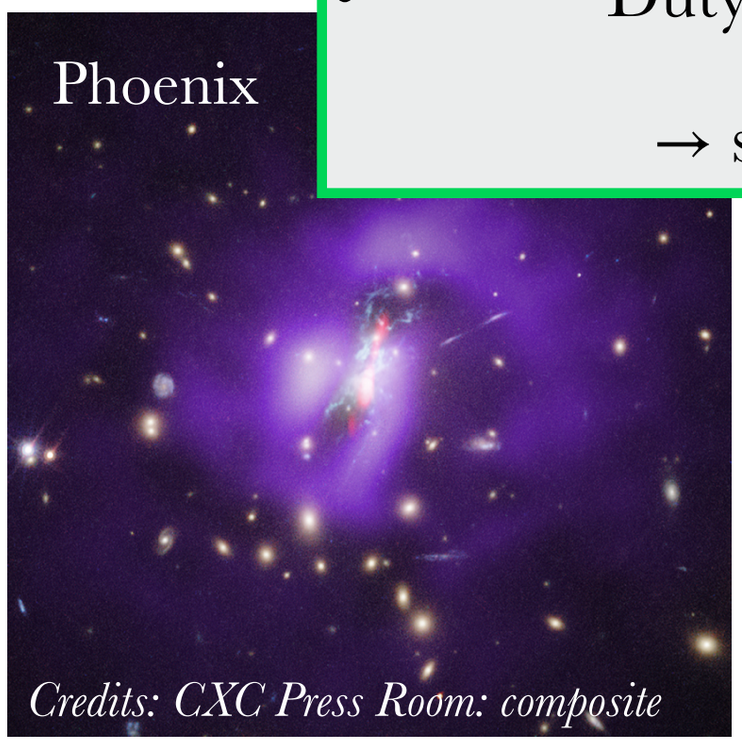
- The role of shock fronts vs cavities in heating the ICM
- How is the energy distributed through the medium, jets changing orientation?
- Duty cycle and timescales of AGN activity

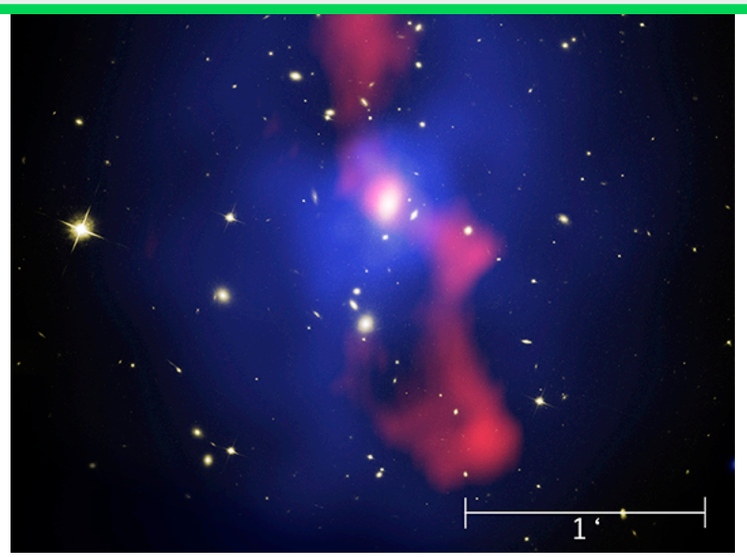
→ superb spatial resolution is needed!

nd to the
al AGN

injecting
he gas

and cold gas
ral AGN





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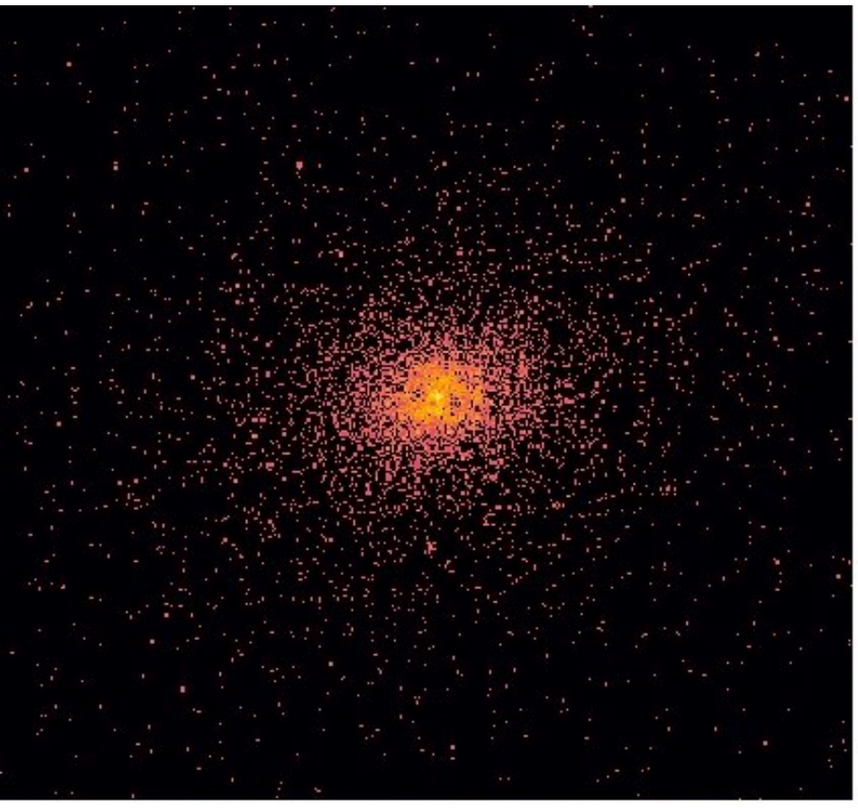
20 years of *Chandra* observations of RBS 797

A remarkable feedback laboratory

2000: 12 ks



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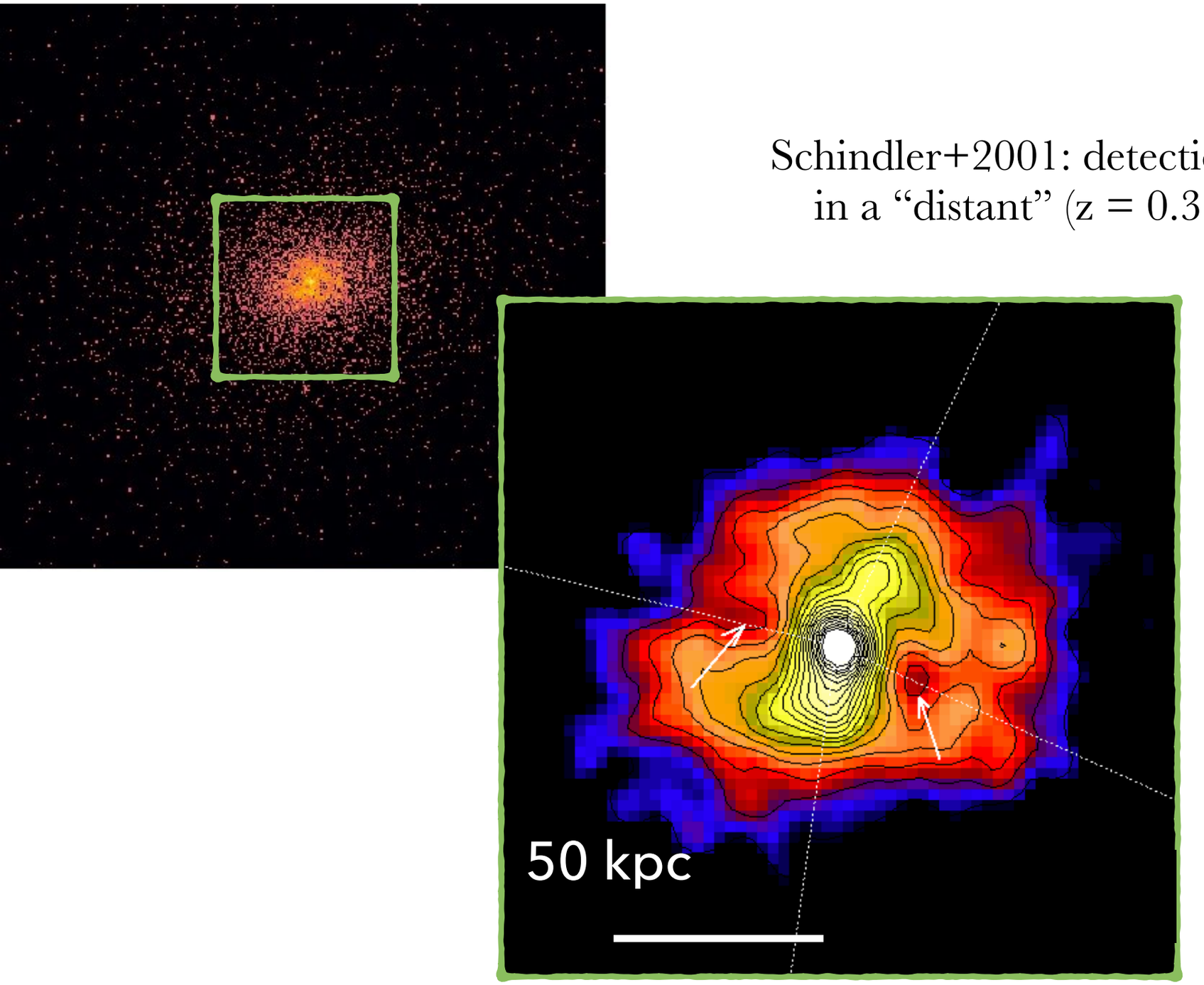

Schindler+2001: detection of X-ray cavities in a “distant” (z = 0.354) galaxy cluster

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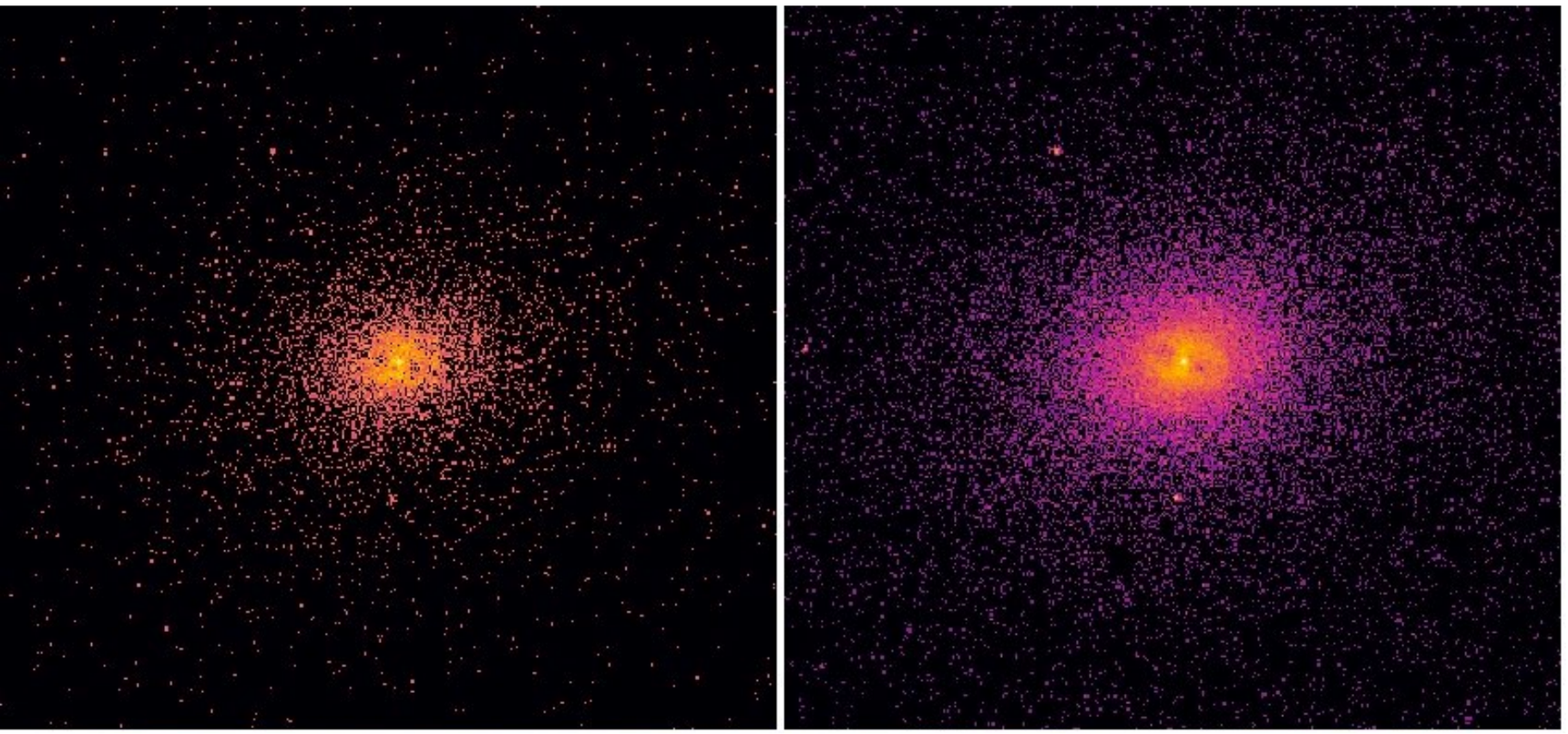

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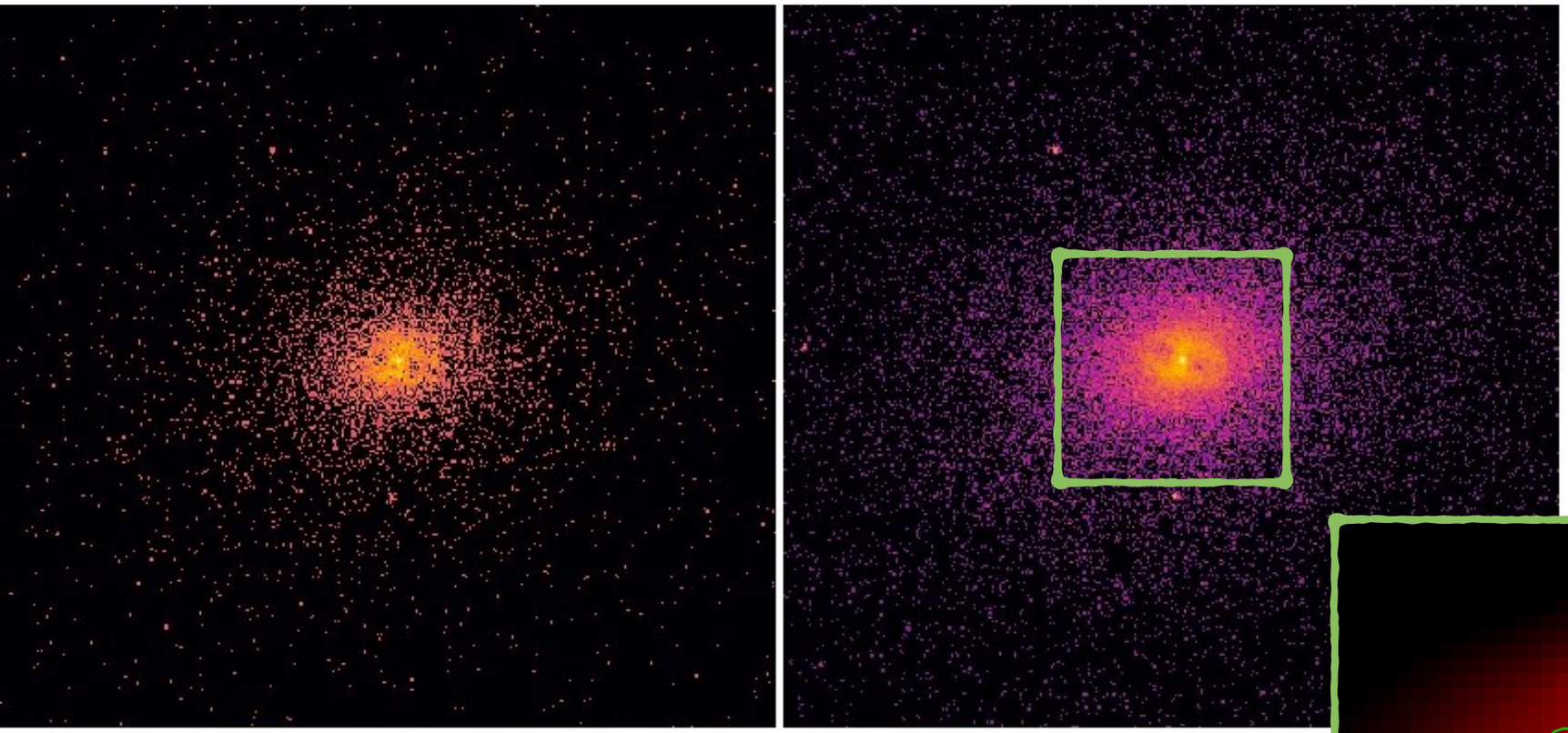

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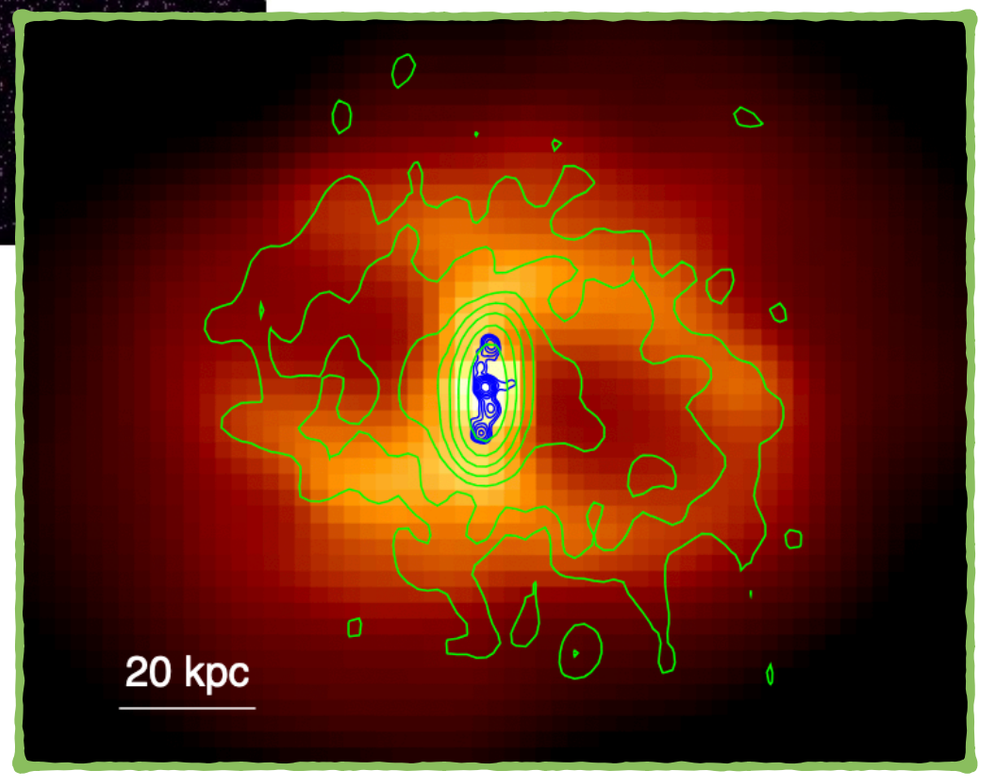
Gitti+2006,2013, Cavagnolo+2011, Doria+2012:

Radio-filled X-ray cavities, but also multiple jets/lobes in different directions!



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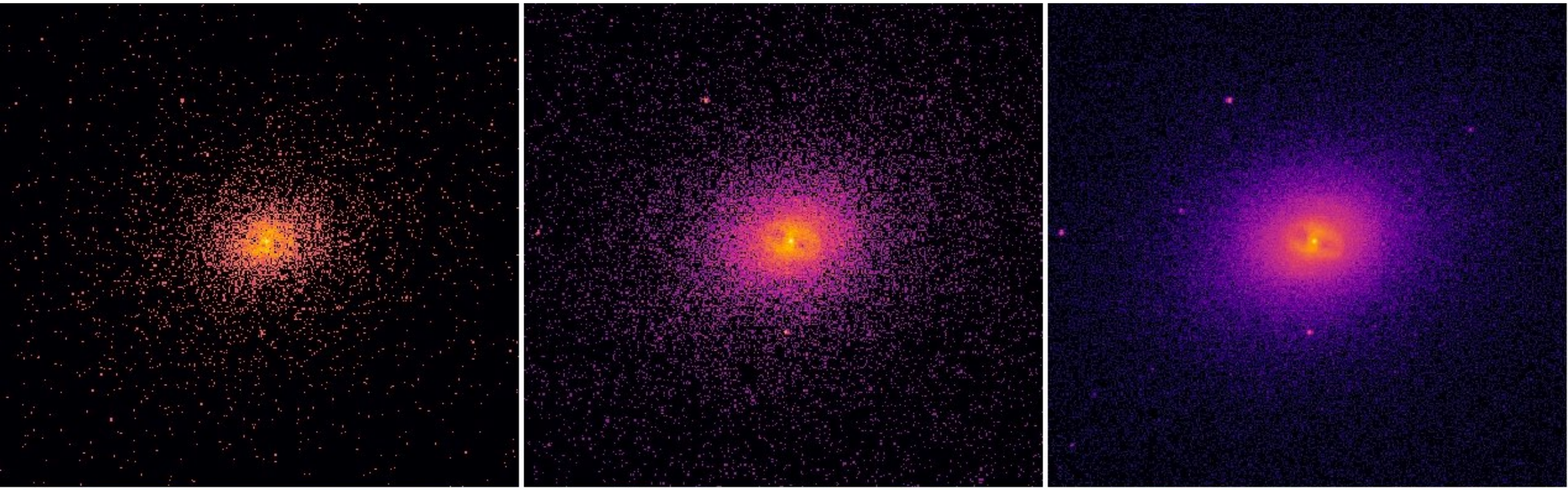
2000: 12 ks

2007: 50 ks

2021: 460 ks



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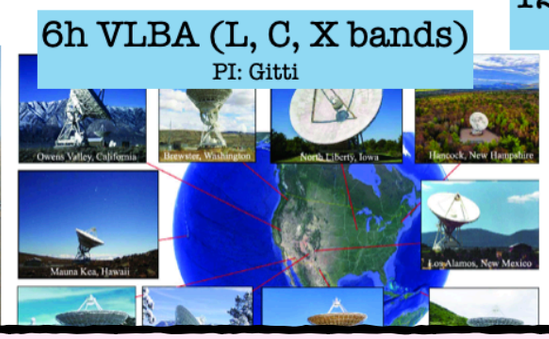
Chandra Large Program
(PI: M. Gitti), ~400 ks!

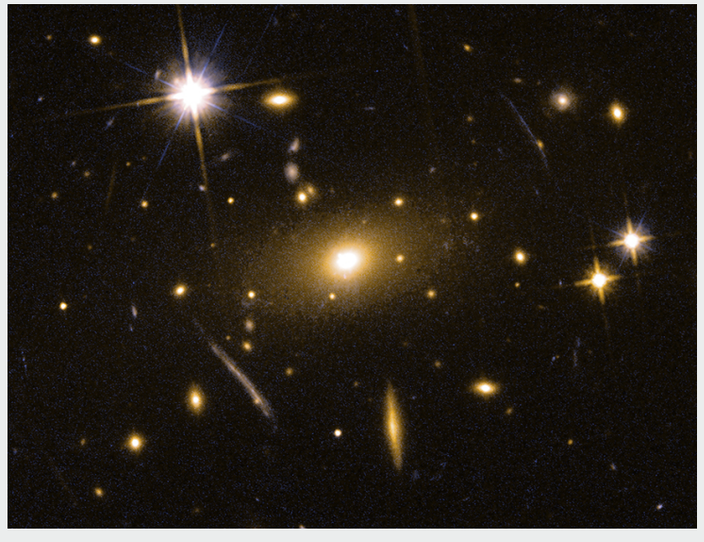
20 years of *Chandra* observations of RBS 797

MULTI-WAVELENGTH, SUB-ARCSEC SYNERGY

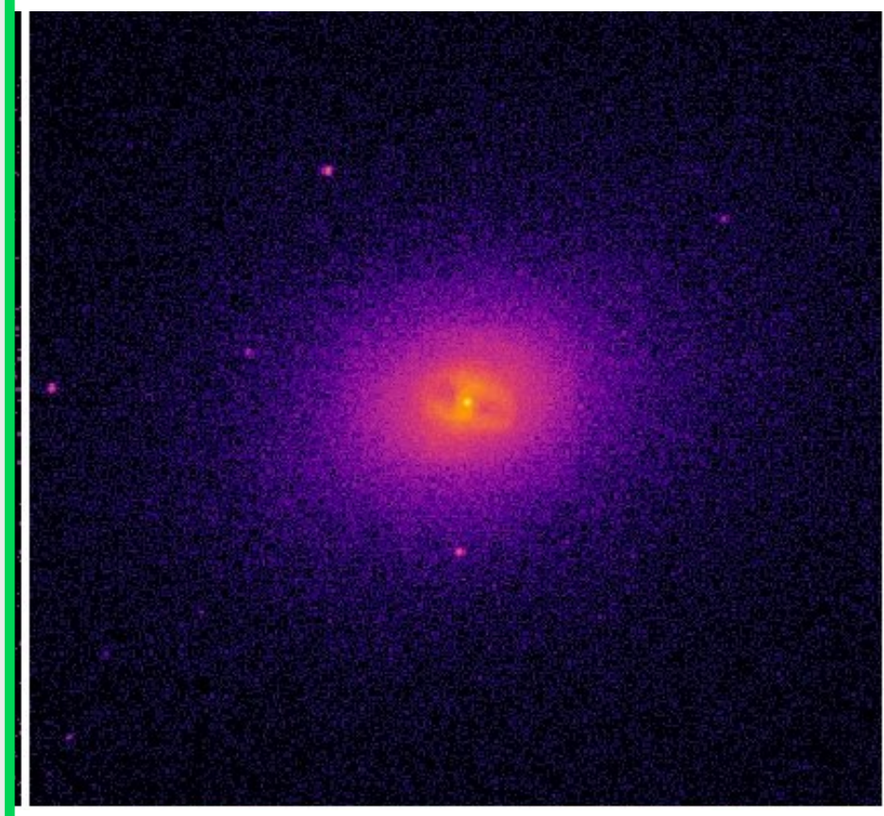


Extensive radio coverage
> 50 hours between 100 MHz - 10 GHZ

Narrowband HST imaging
7 orbits



2021: 460 ks



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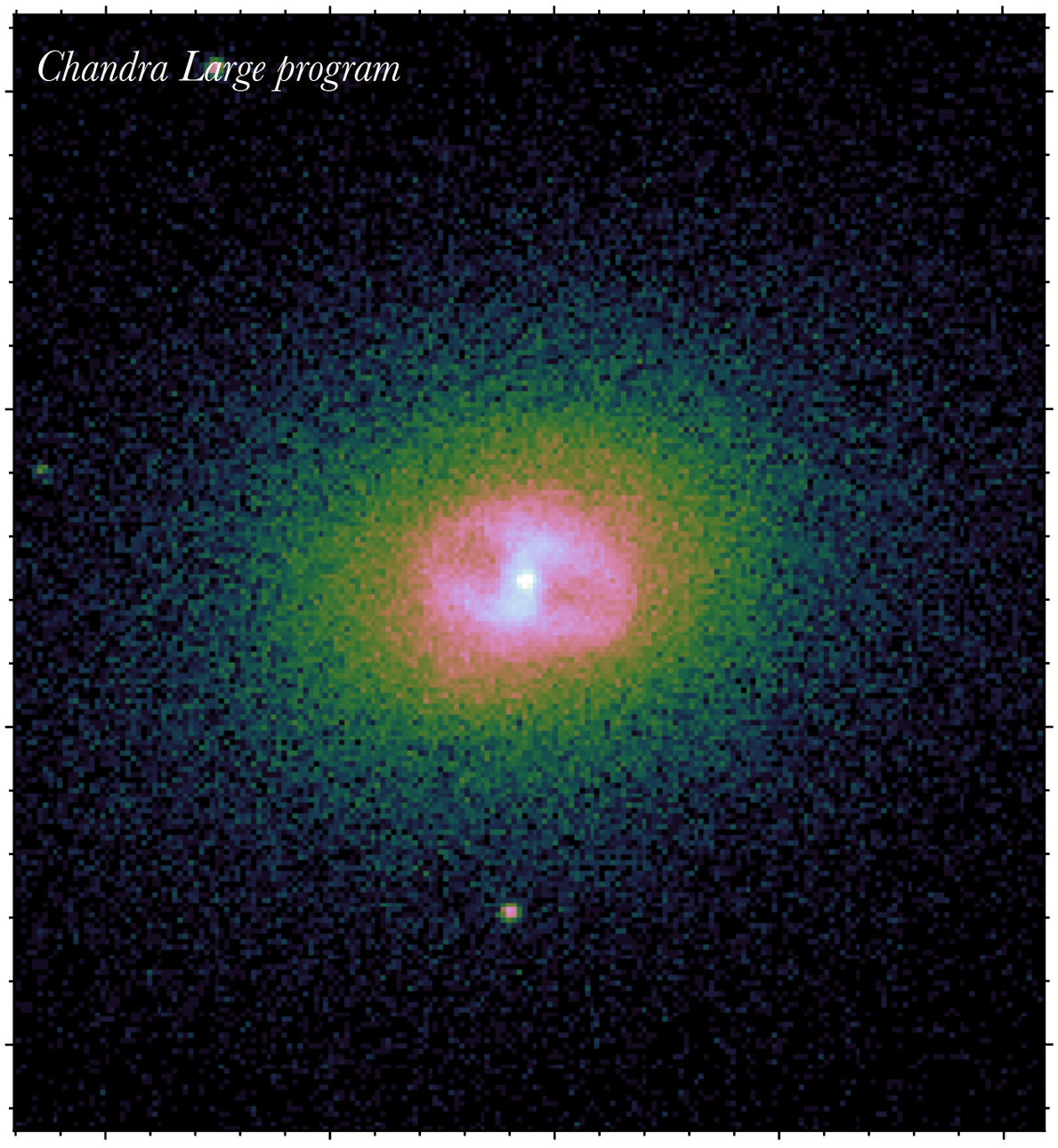
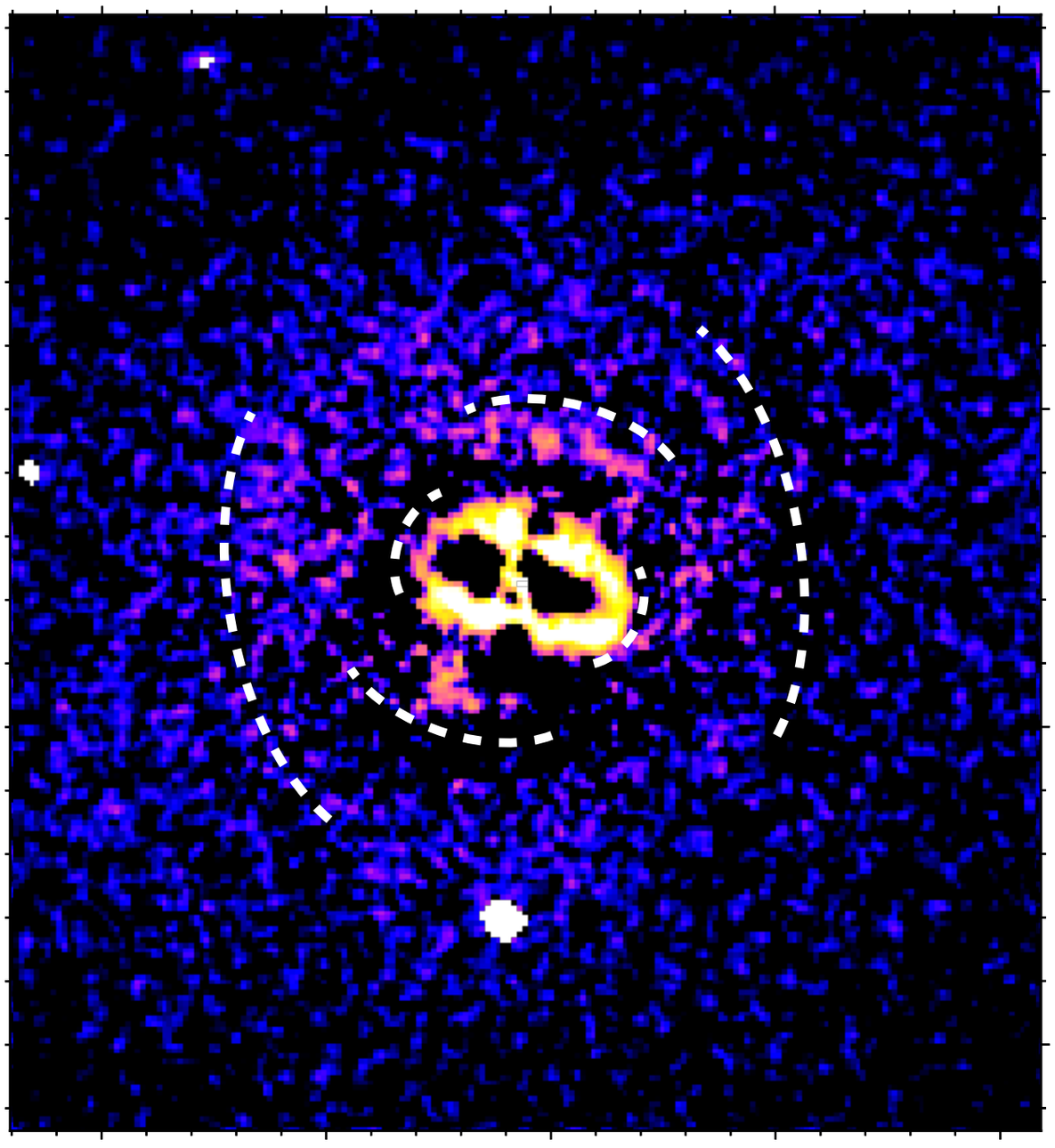
(PI: M. Gitti), ~400 ks!

Ubertosi et al. 2021, 2023b, 2024
+ Calzadilla et al. 2022, Bonafede et al. 2023

25 Years of Chandra science - francesco.ubertosi2@unibo.it

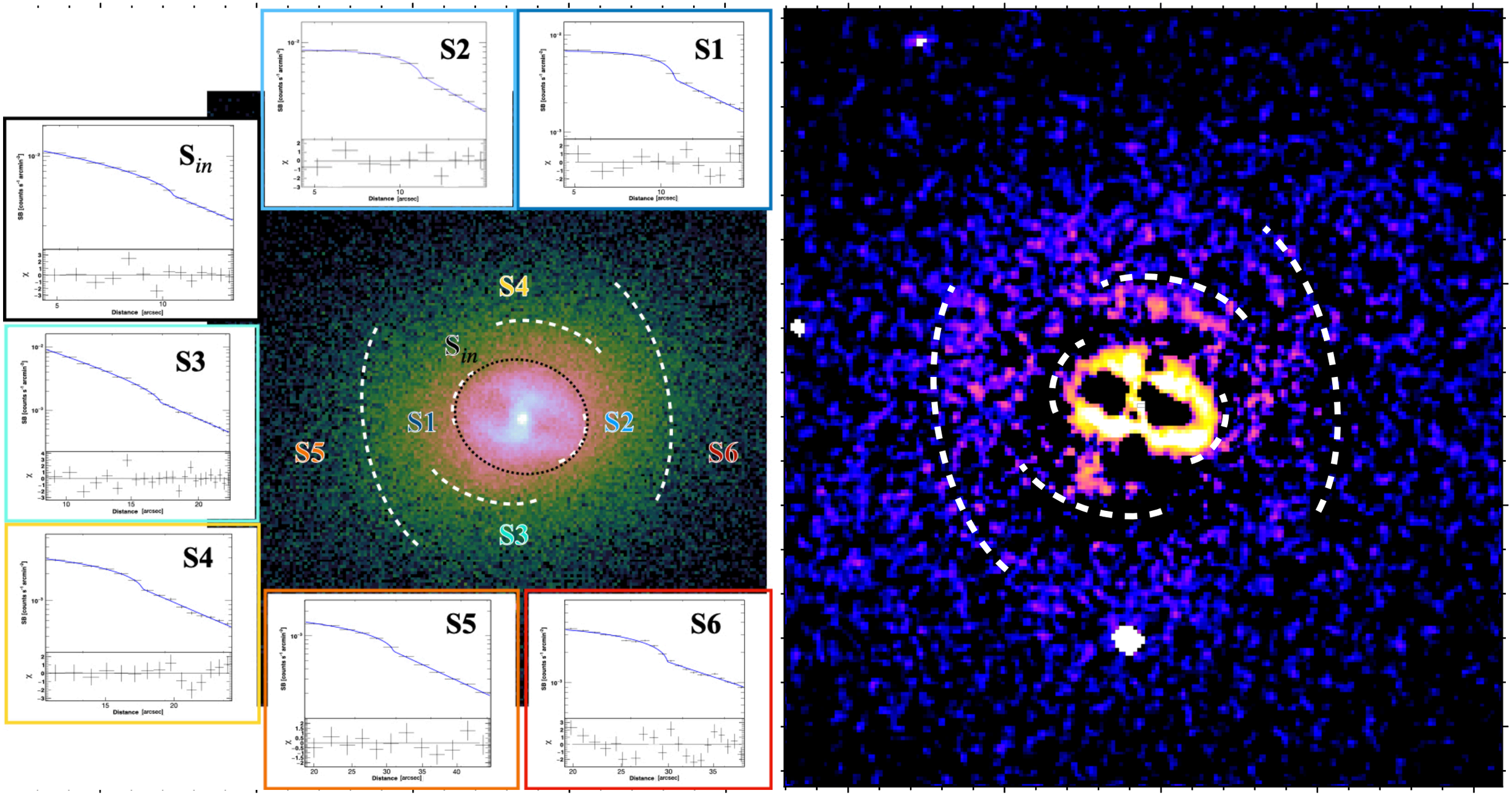
A plethora of feedback features: shock fronts





Ubertosi et al. 2021, 2023b

A plethora of feedback features: shock fronts



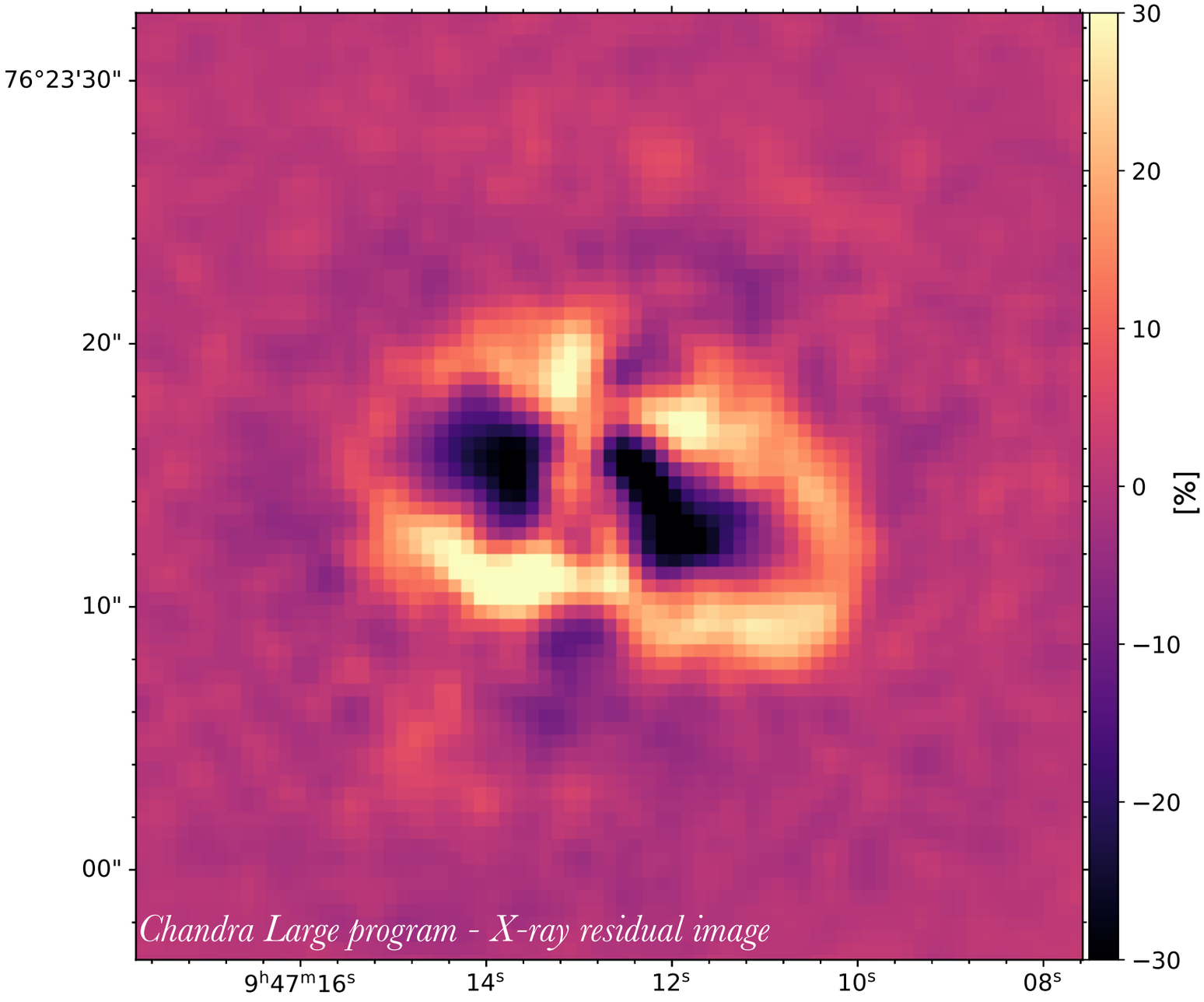
CONFIRMED AS TEMPERATURE JUMPS!

***Ubertosi et al.* 2021, 2023b**

3 concentric AGN-driven shock fronts within 130 kpc from the center

$\mathcal{M} \sim 1.3$, $P_{jet} > 10^{46}$ erg/s

A plethora of feedback features: X-ray cavities



Ubertosi et al. 2021, 2023b

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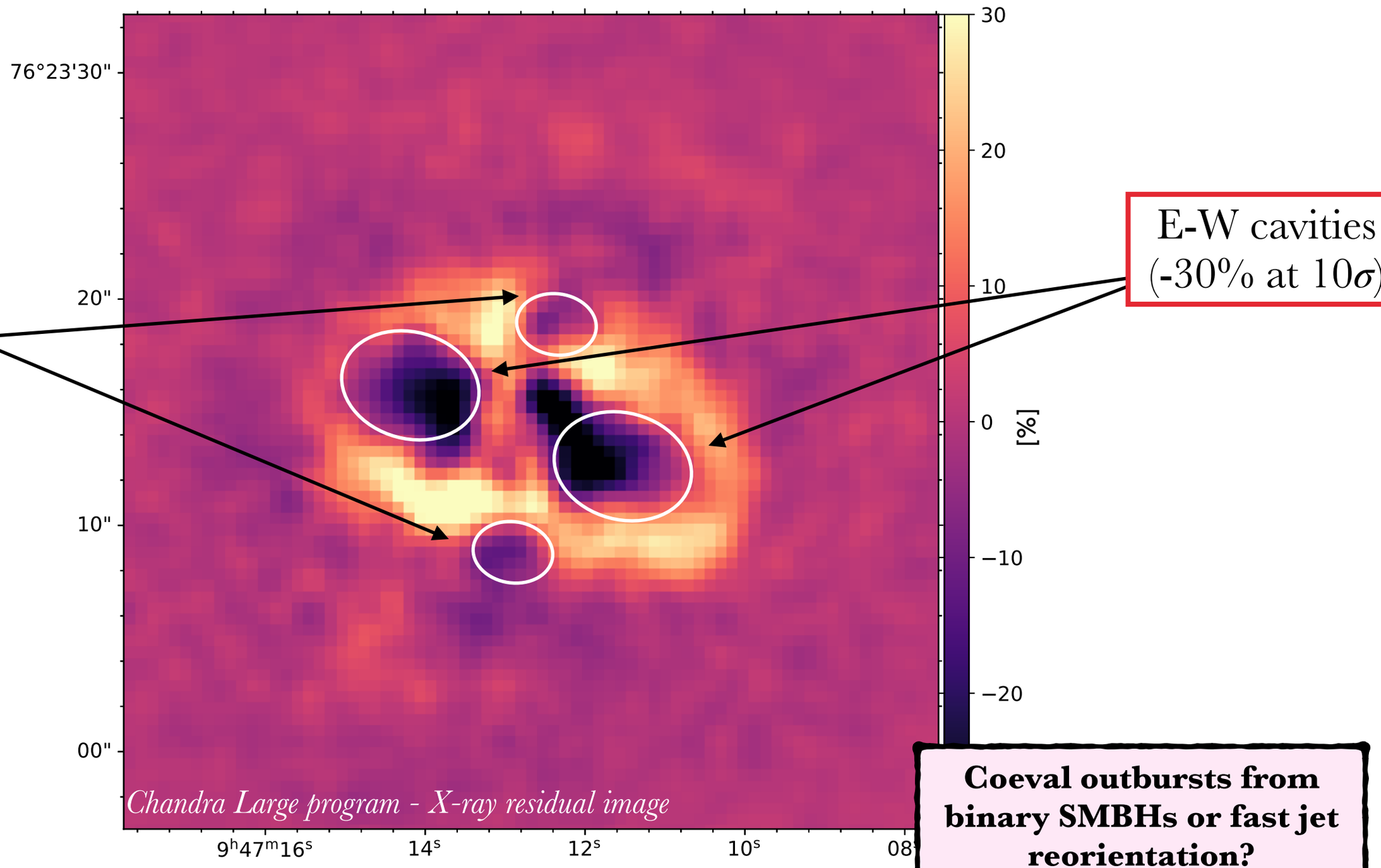


N-S cavities
(-10% at 4σ)

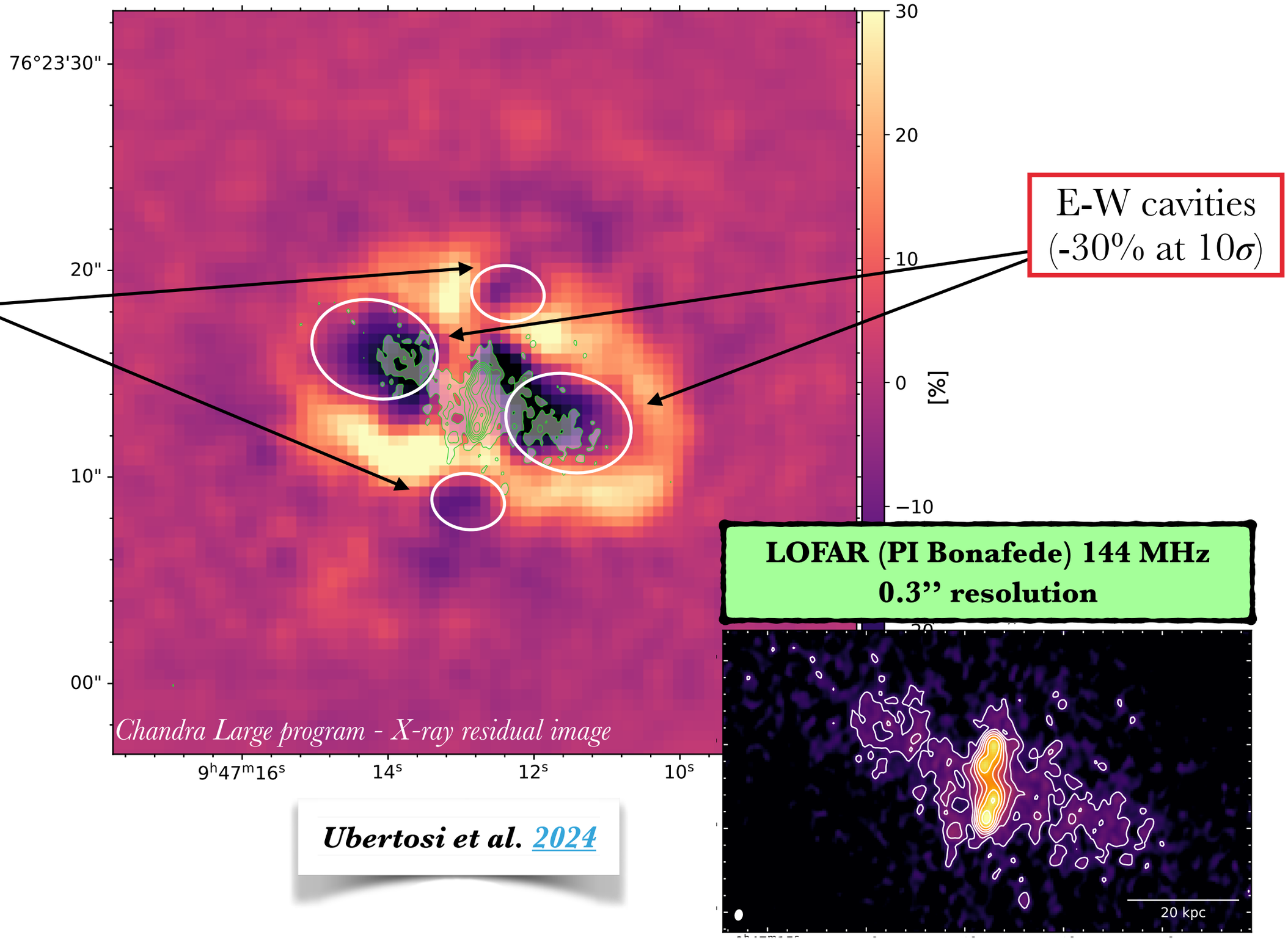
E-W cavities
(-30% at 10σ)

Ubertosi et al. 2021, 2023b

Coeval outbursts from binary SMBHs or fast jet reorientation?

See NASA press release: https://chandra.harvard.edu/photo/2021/rbs797/

The sub-arc second synergy: LOFAR and JVLA



Ubertosi et al. 2024

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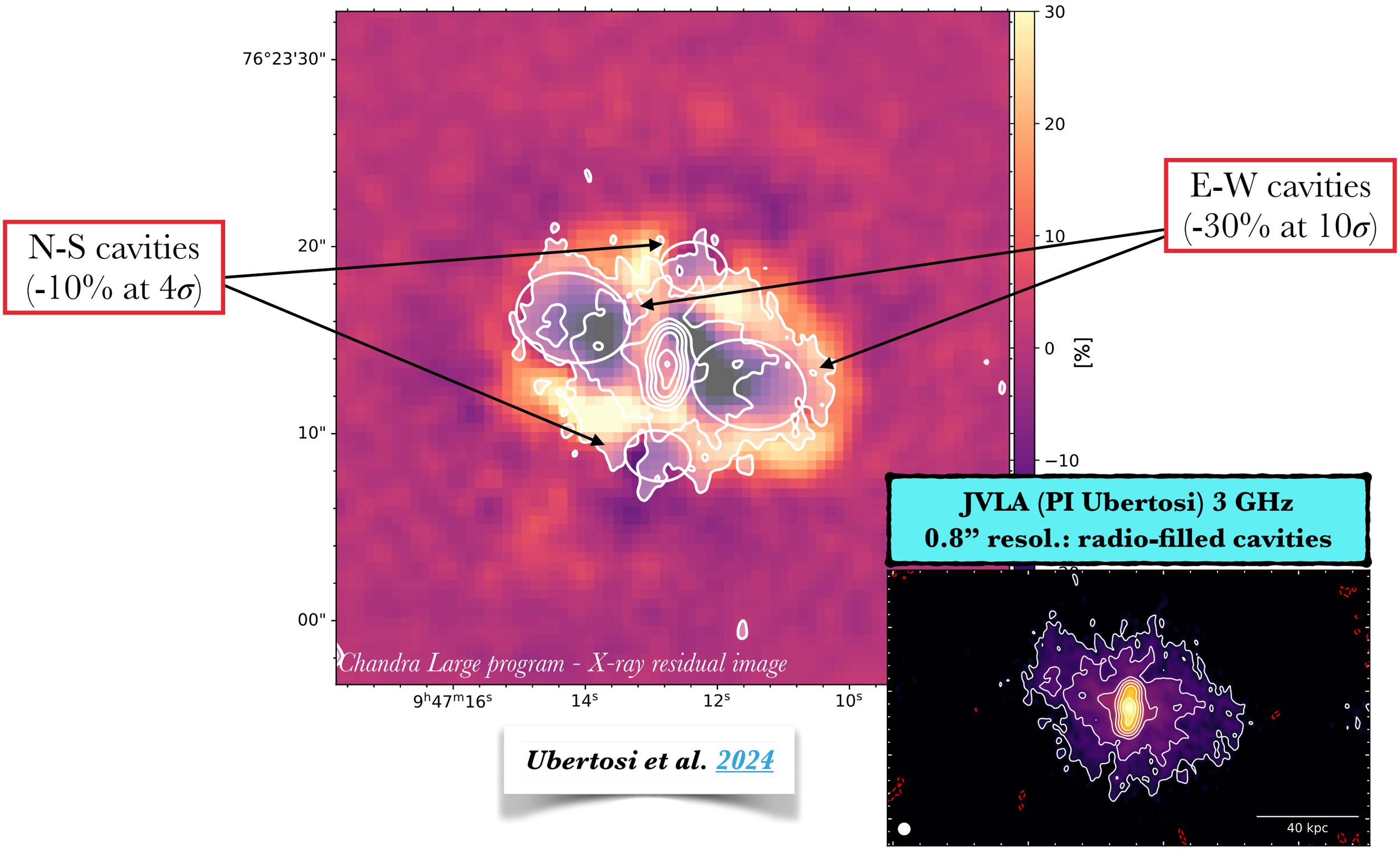


Ubertosi et al. 2024

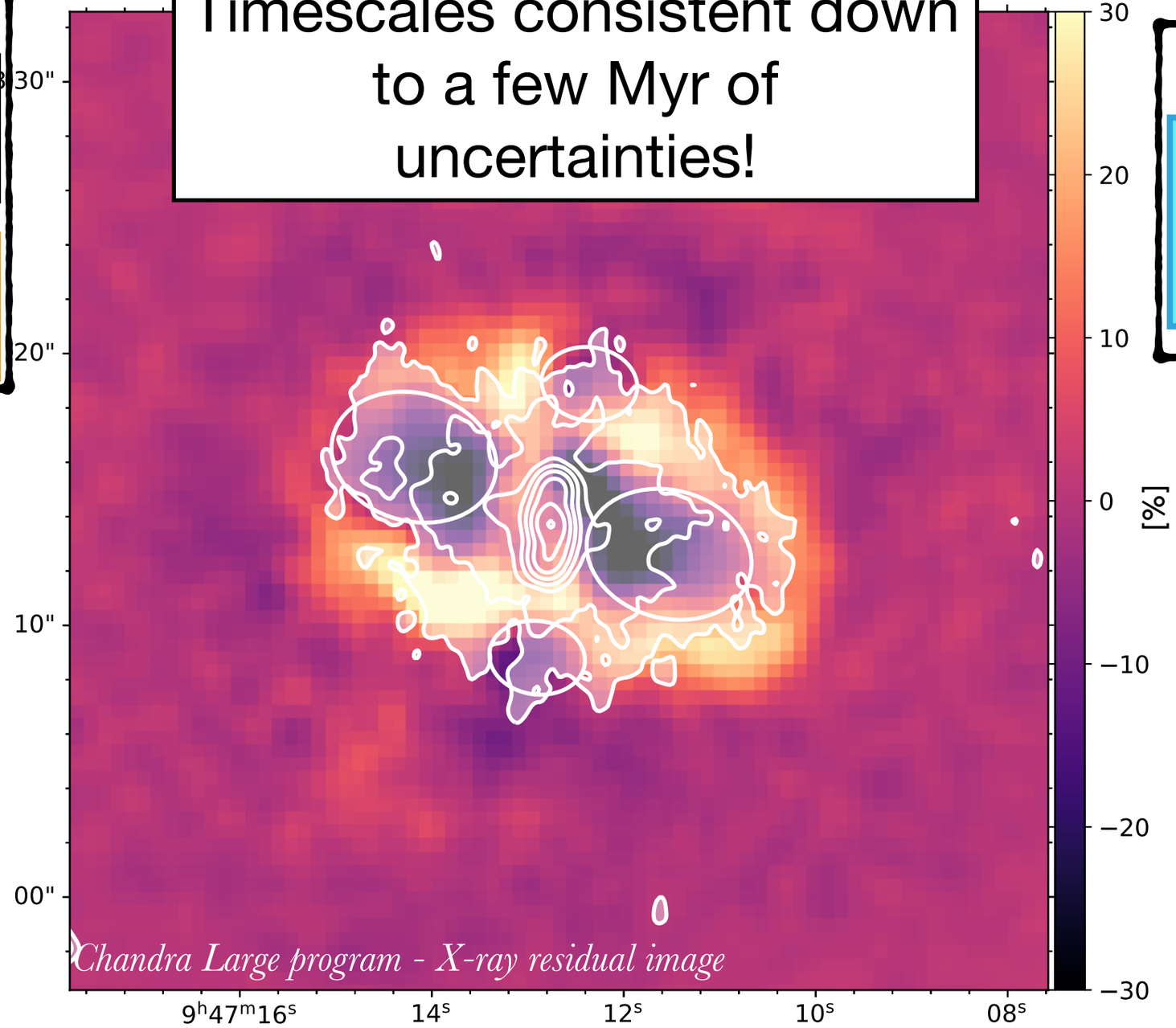
The sub-arc second synergy: the **timescales**

DYNAMICAL

X-ray cavities:
30 ± 9 Myr

Shock front:
33 ± 2 Myr

Timescales consistent down to a few Myr of uncertainties!

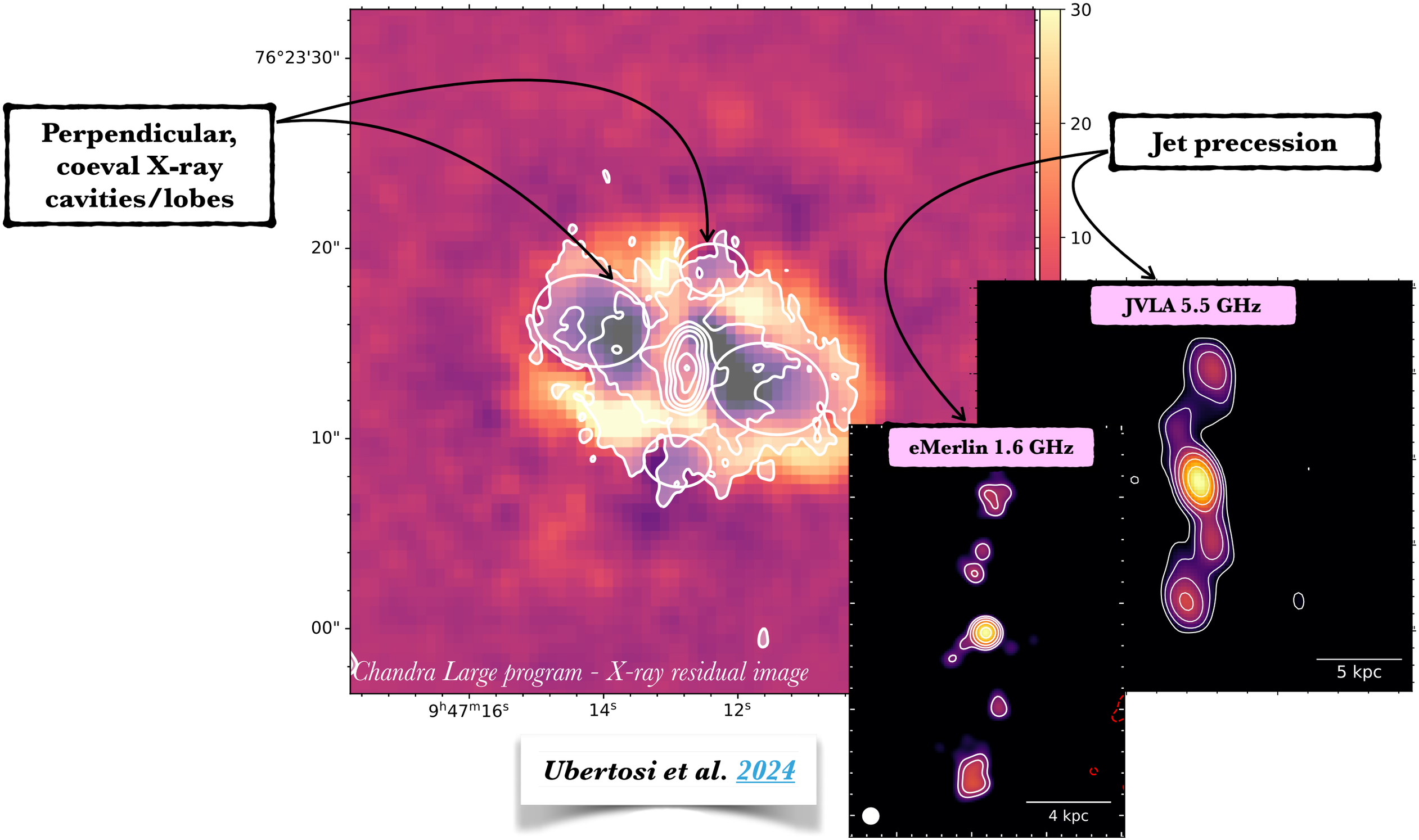


RADIATIVE

Radio lobes:
31 ± 7 Myr
32 ± 8 Myr

Ubertosi et al. 2024

The sub-arc second synergy: eMerlin & VLBI



Ubertosi et al. 2024

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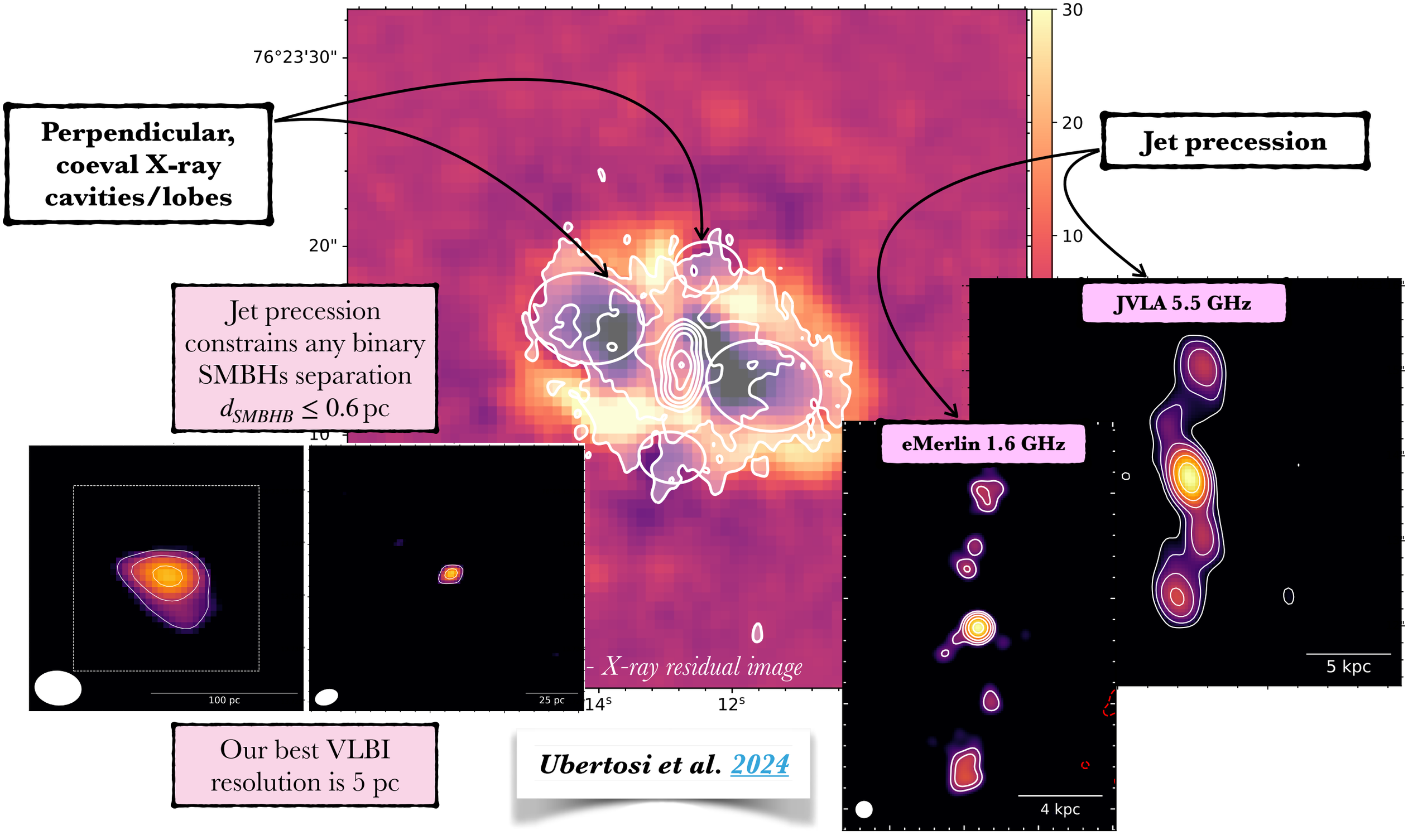
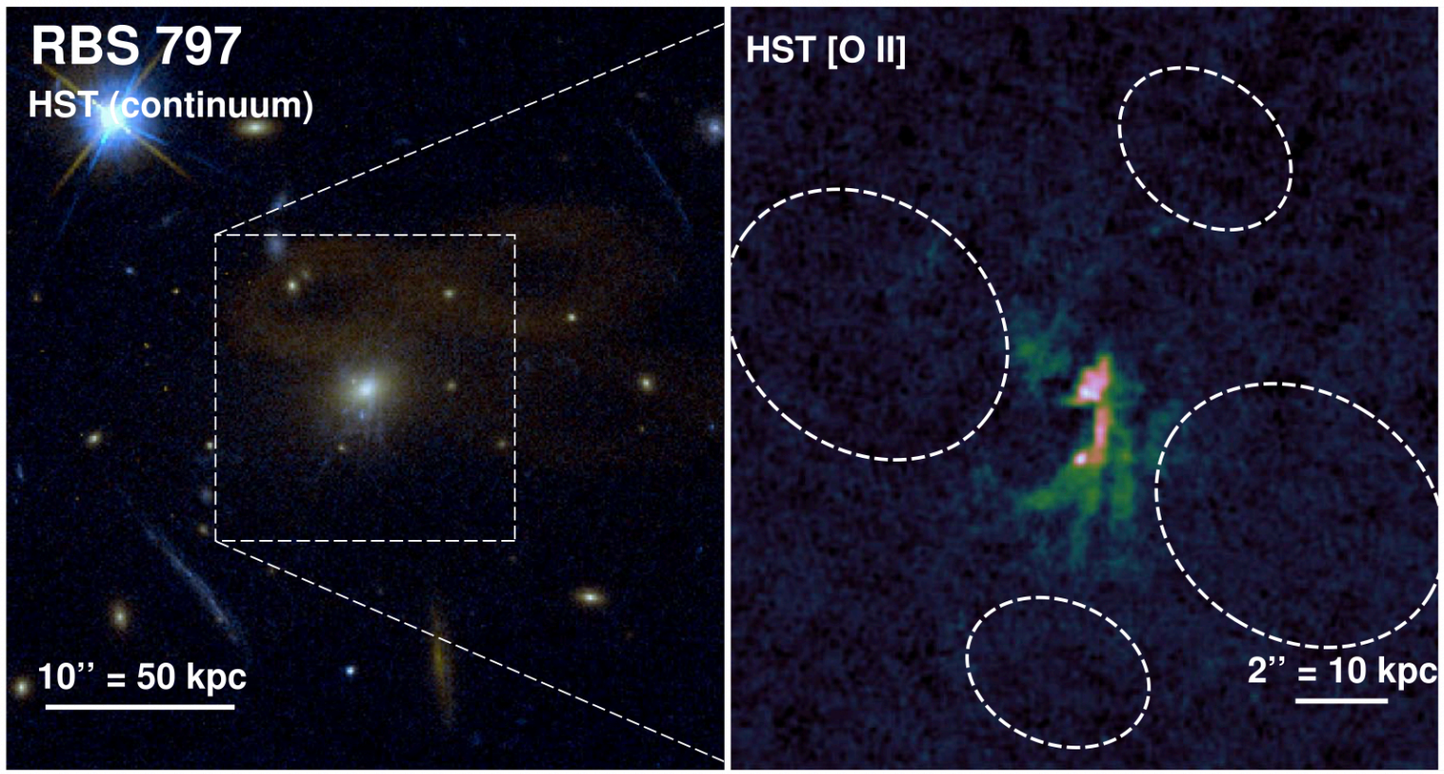


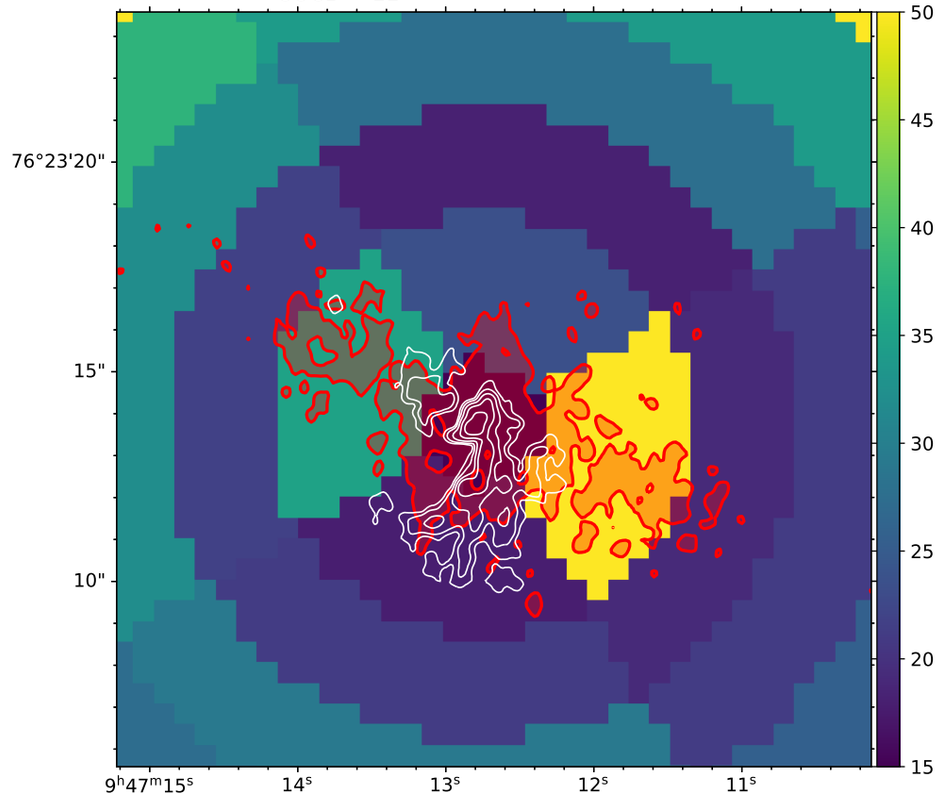
The sub-arc second synergy: HST

Hubble Space Telescope: continuum & [OII]



Warm gas filaments tracing SF regions

Chandra: t_{cool}/t_{ff} (*HST* + LOFAR contours)

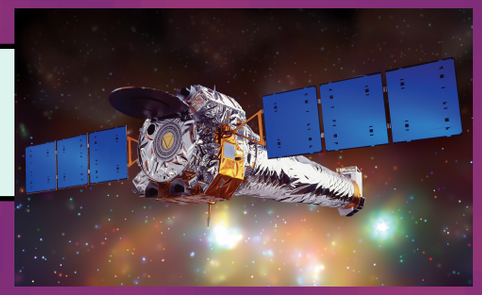


Lowest t_{cool}/t_{ff} → high [OII] luminosity

Calzadilla et al. 2022

Ubertosi et al. 2023b

Summary & Conclusions



Remarkable AGN feedback laboratory:

Multiple X-ray cavities

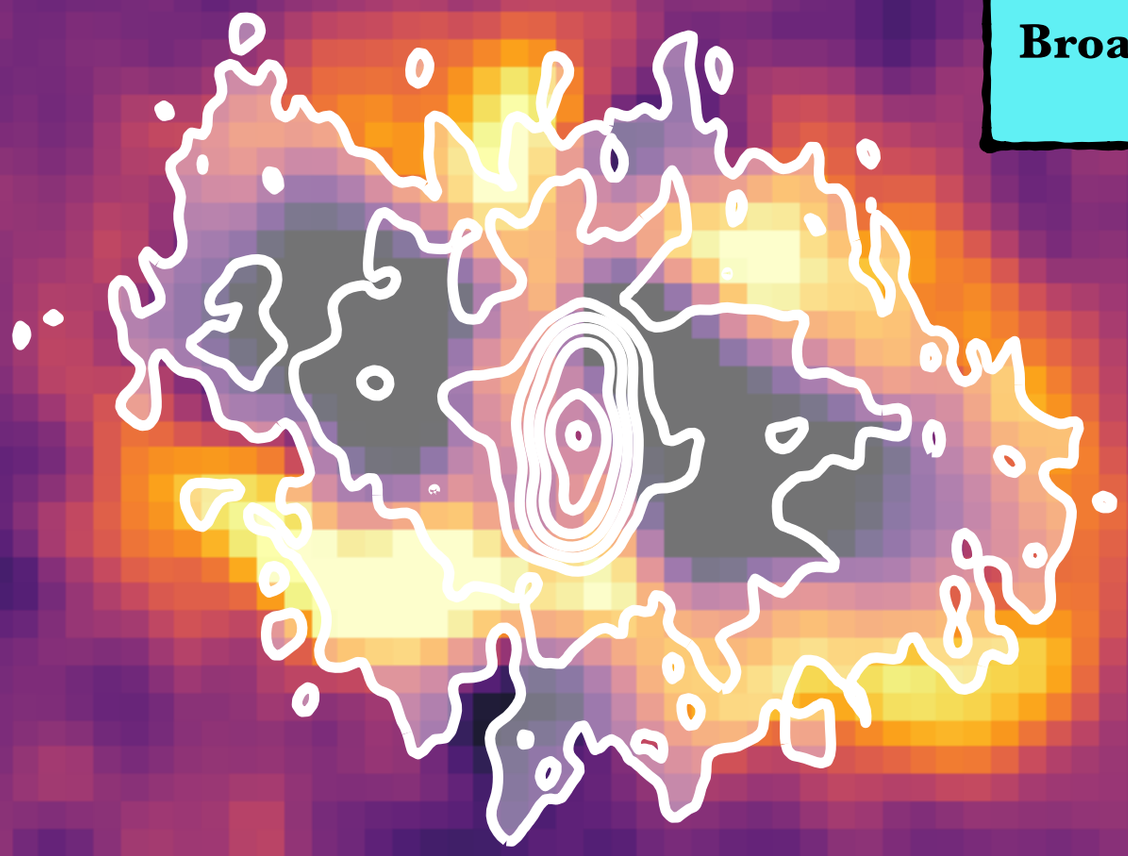
Multiple shock fronts

458 ks Chandra Large Program

+ HST

+ LOFAR, JVLA, eMerlin, EVN, VLBA

Broad (10^5) range of spatial scales at sub-arc sec resolution



Dynamics and timescales of AGN activity

Coeval cavities, shock fronts, and radio lobes

Timing of the SMBH activity over 80 Myr with a precision of ≈ Myr

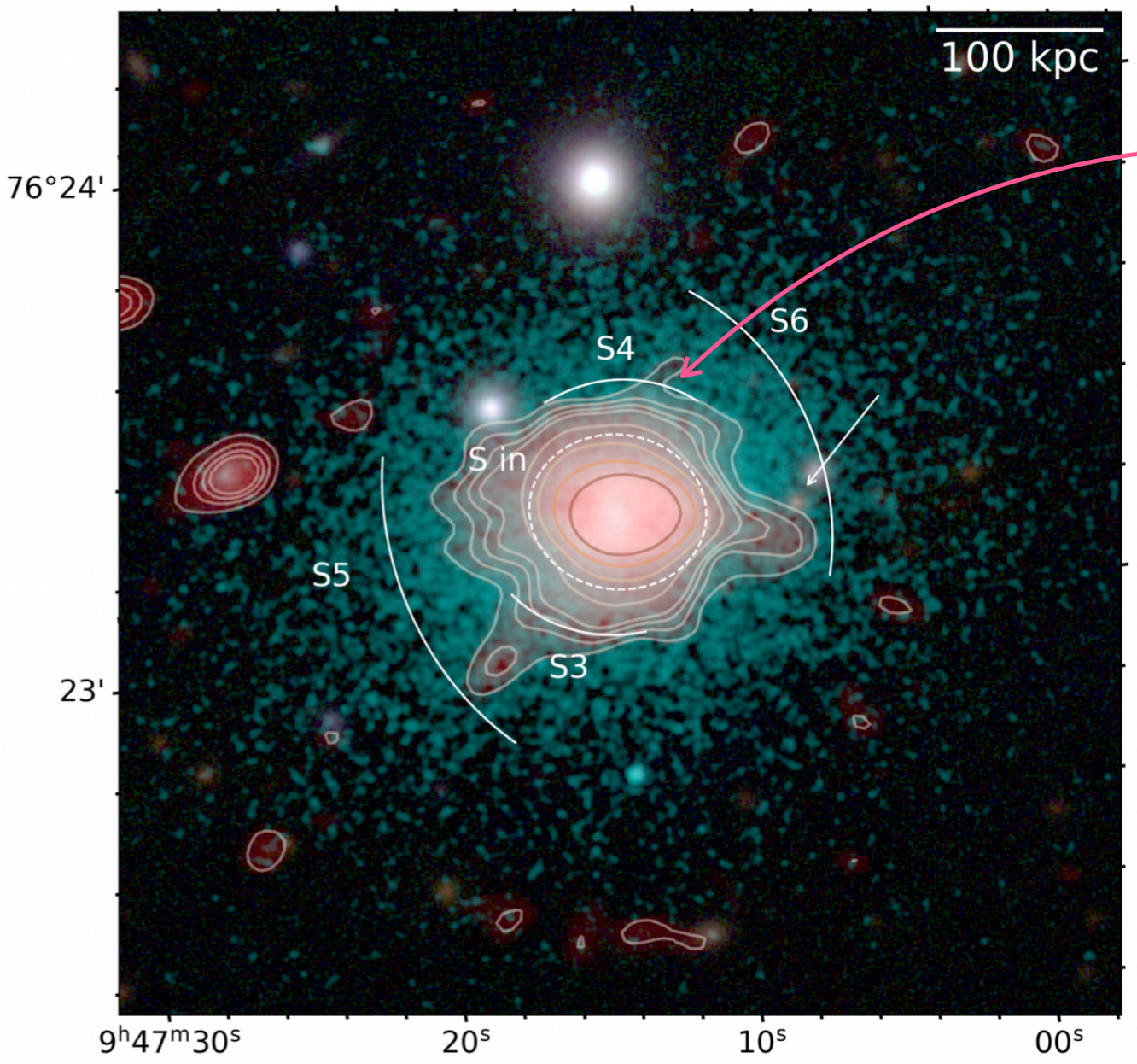
Jet precession and reorientation

25 Years of Chandra science - francesco.ubertosi2@unibo.it

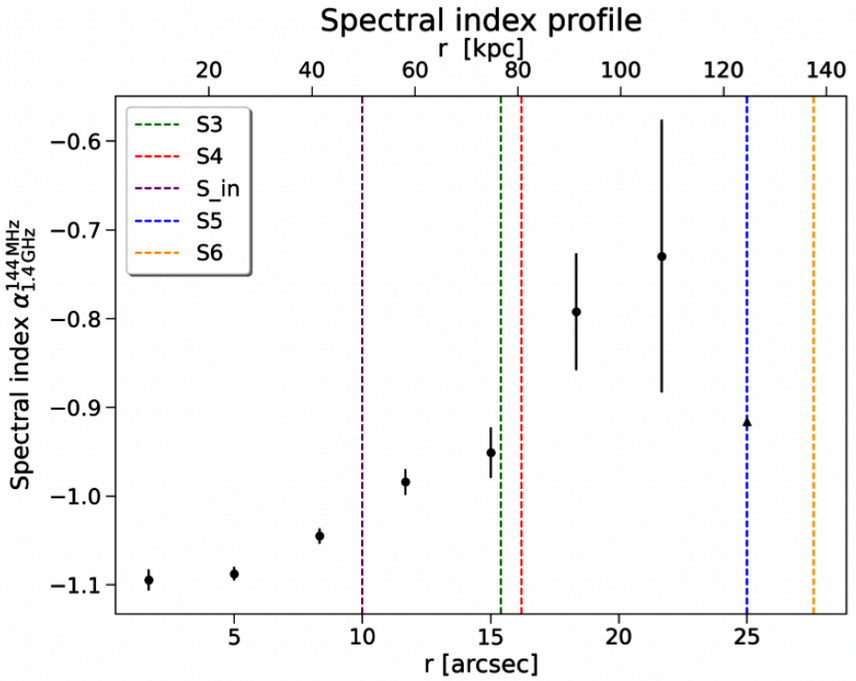
20 years of *Chandra* observations of RBS 797

BACKUP SLIDES

A DIFFUSE RADIO MINI-HALO RE-ACCELERATED BY THE SHOCK FRONTS?



Radio mini-halo "caged" within the middle shock fronts



Spectral index of the mini halo flattens approaching the shock front → particle re-energization?

JVLA POLARIZATION STUDY NEXT! (PI: Ubertosi)

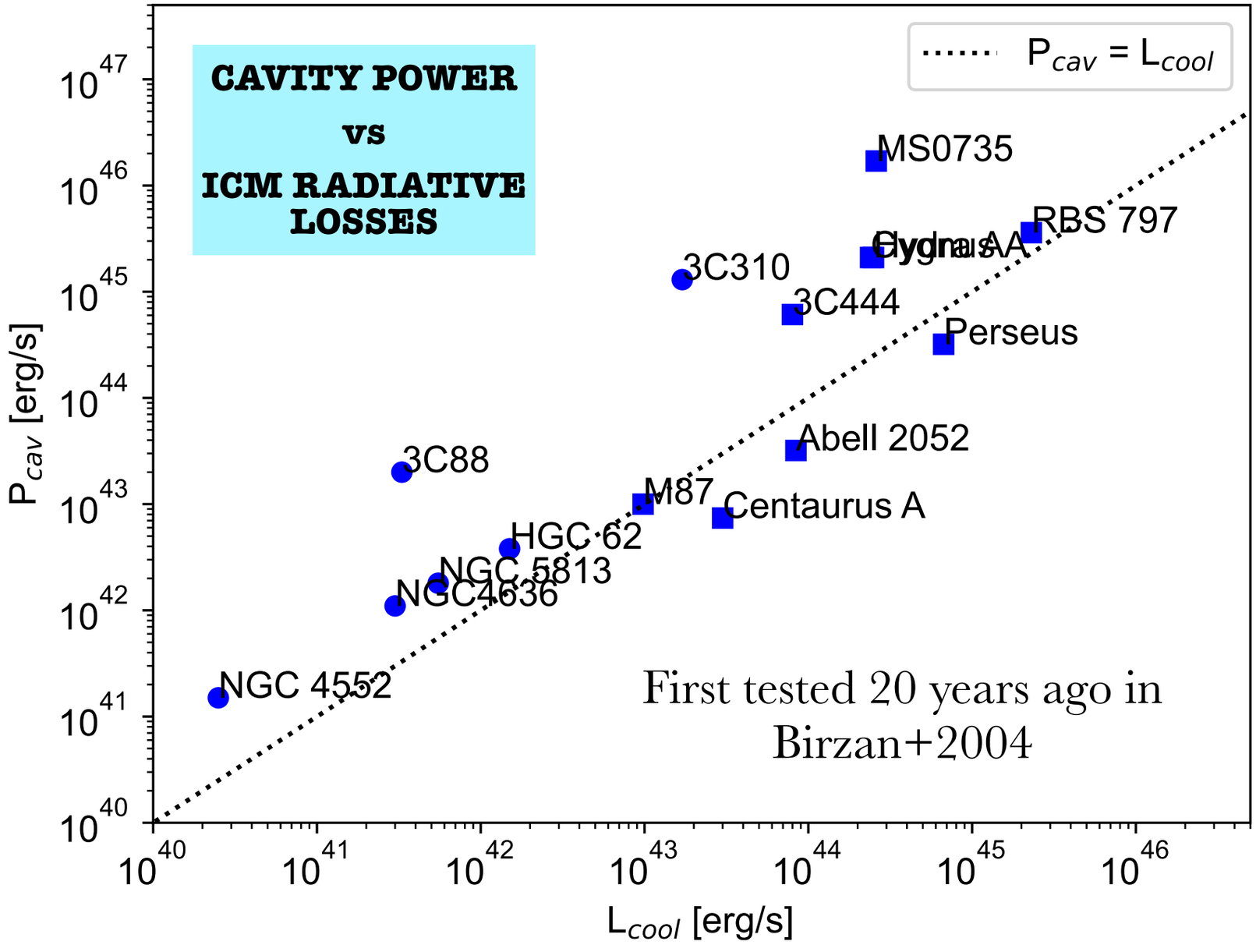
Bonafede et al. 2023

25 Years of Chandra science - francesco.ubertosi2@unibo.it

AGN-DRIVEN SHOCK FRONTS AND THEIR ROLE IN FEEDBACK

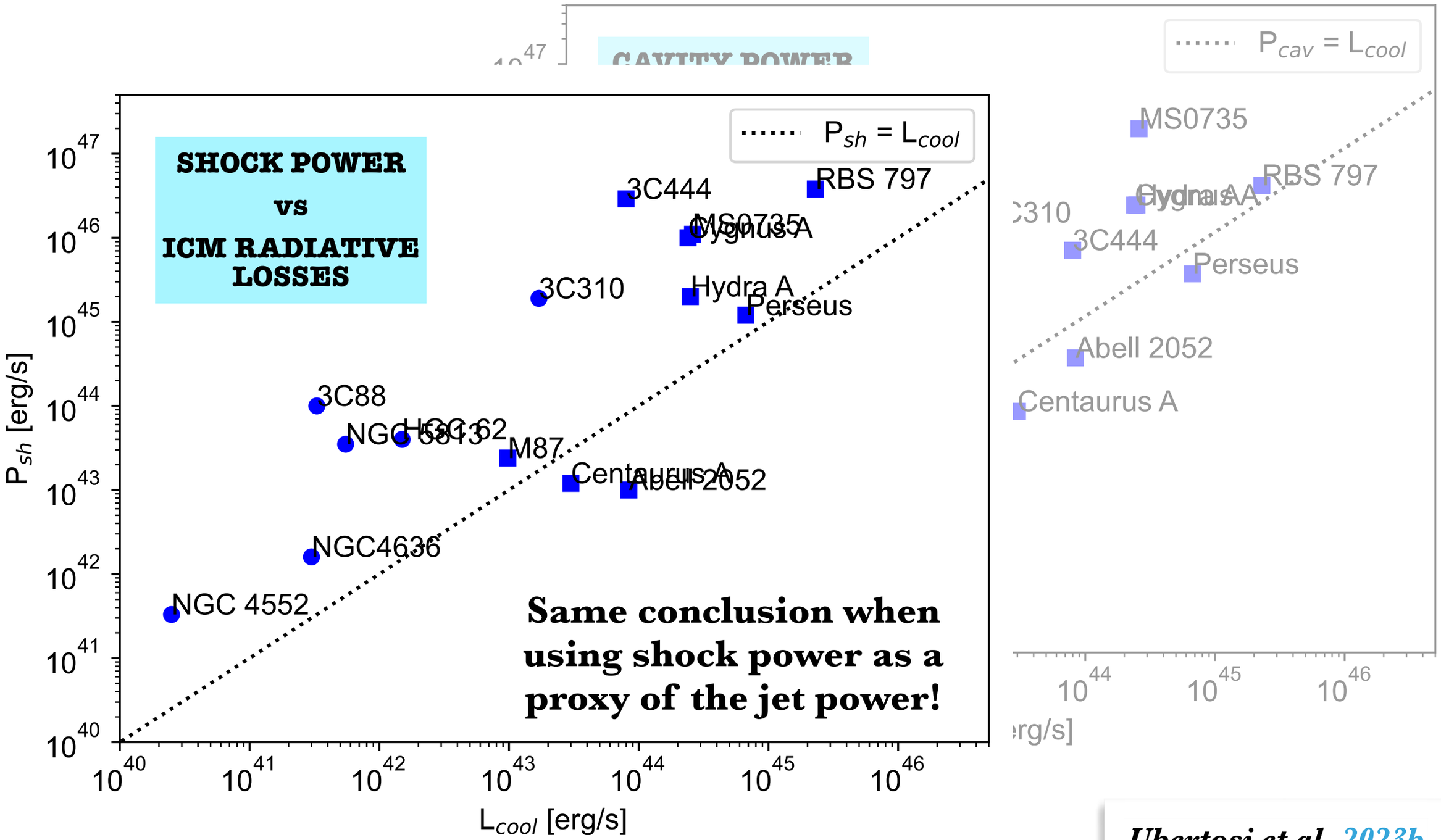
We assembled a compilation of 15 galaxy clusters and groups with detections of both X-ray cavities and shock fronts generated by AGN feedback

Can we provide information on feedback **from shock fronts?**



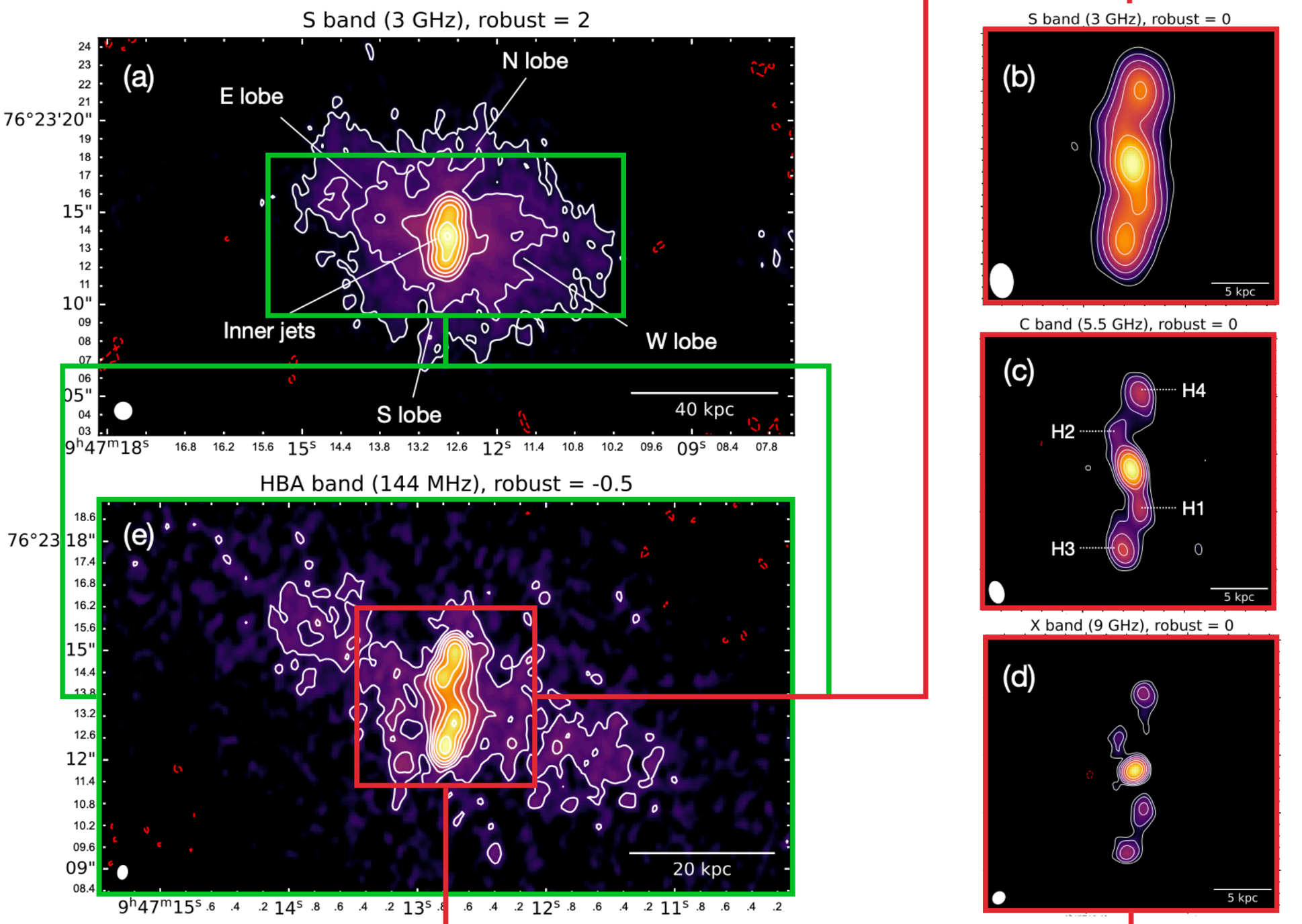
Ubertosi et al. 2023b

AGN-DRIVEN SHOCK FRONTS AND THEIR ROLE IN FEEDBACK



Ubertosi et al. 2023b

The radio view of RBS 797: multiple, differently oriented AGN outbursts



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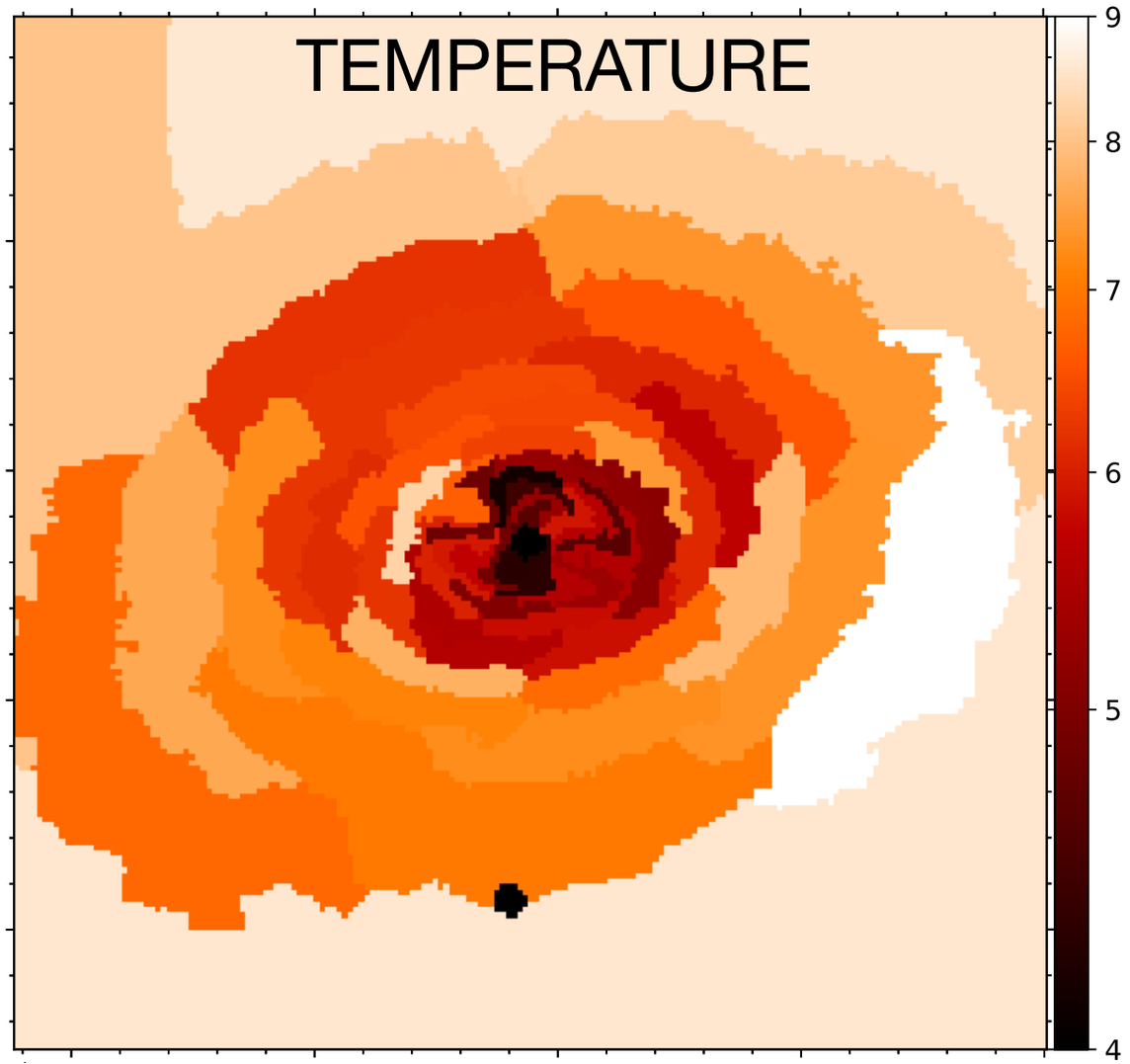
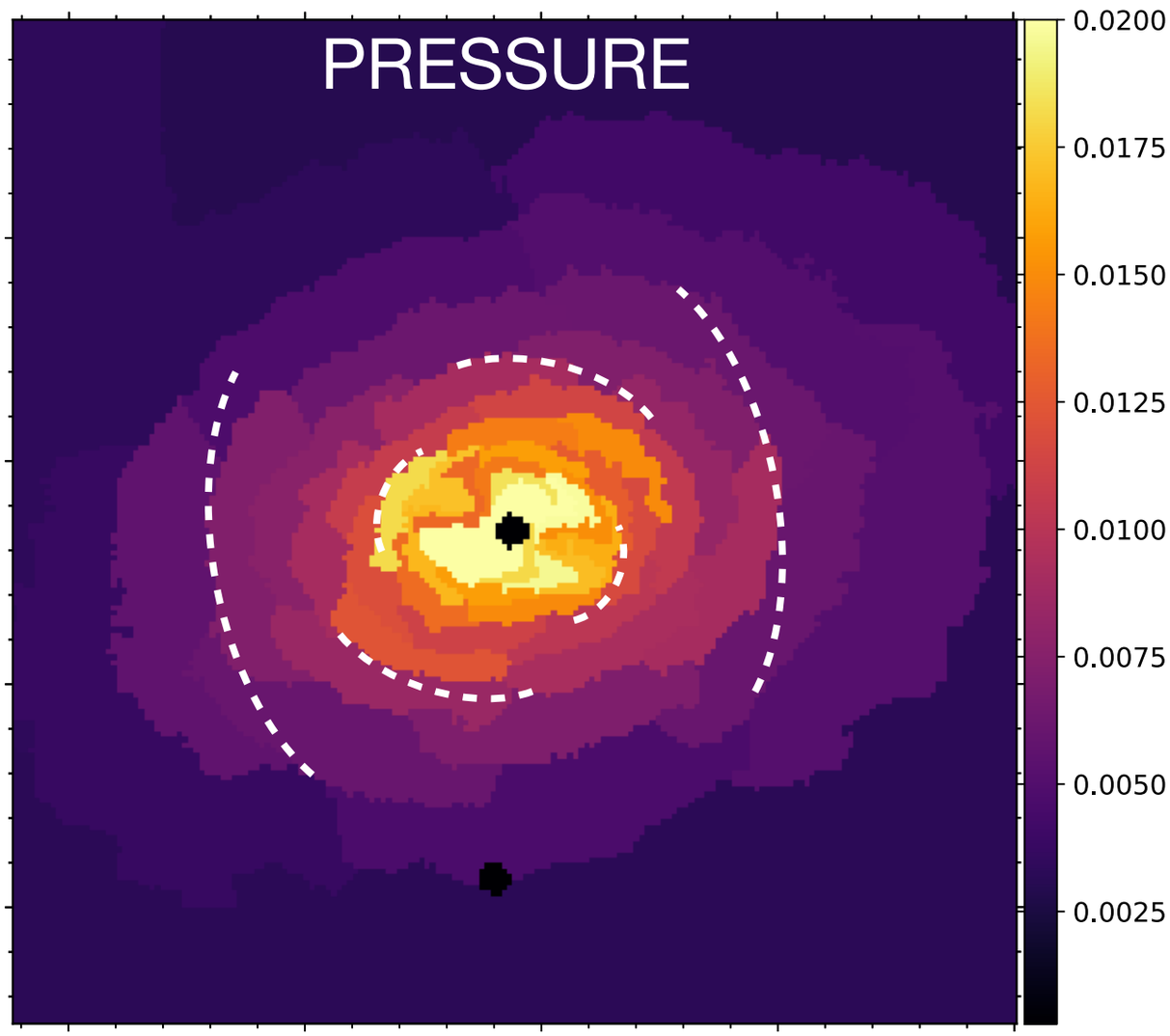
SPECTRAL MAPS OF THE ICM FROM CHANDRA DATA





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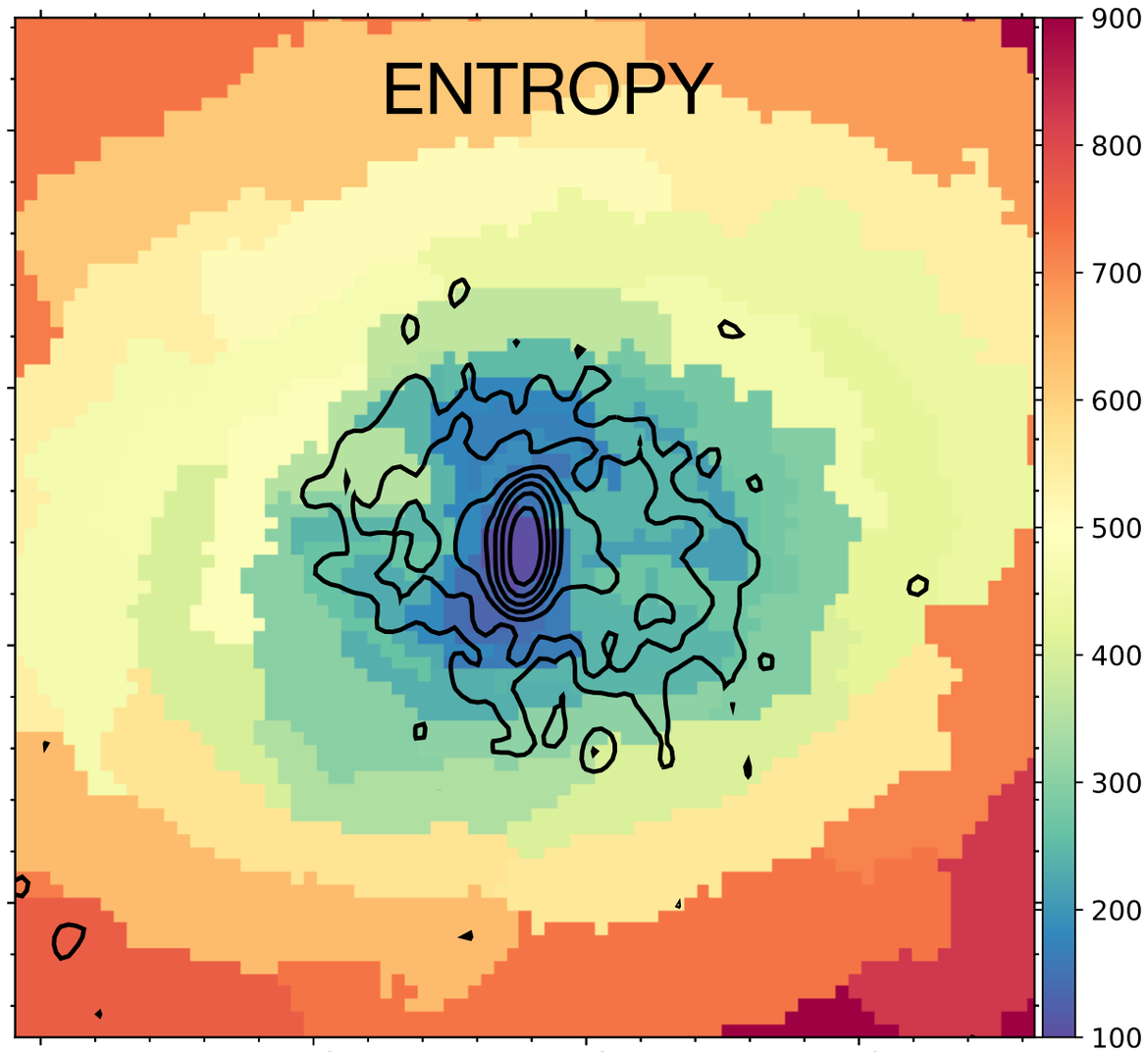

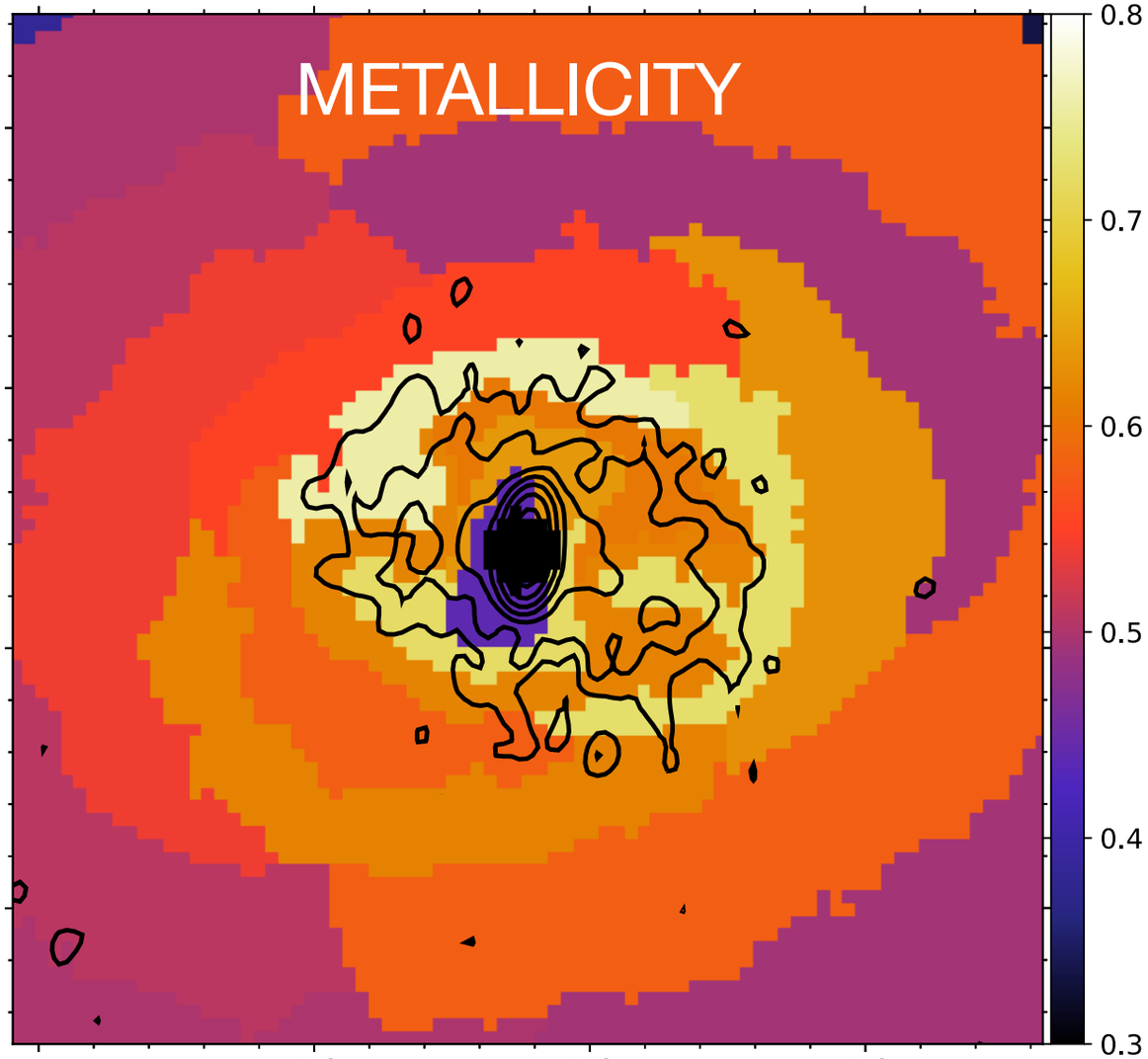

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