Recent Observations of AGN Feedback in Clusters of Galaxies

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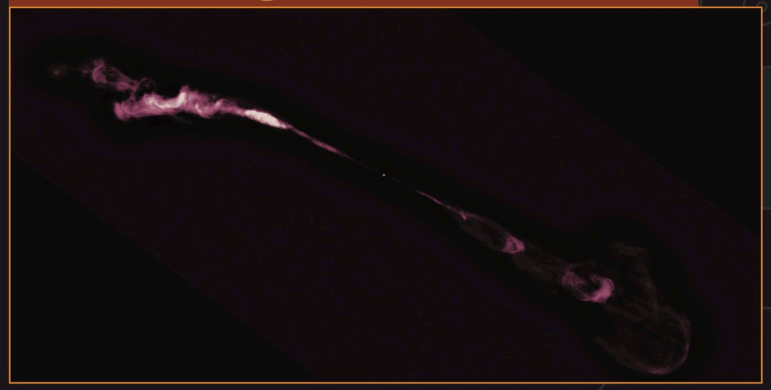
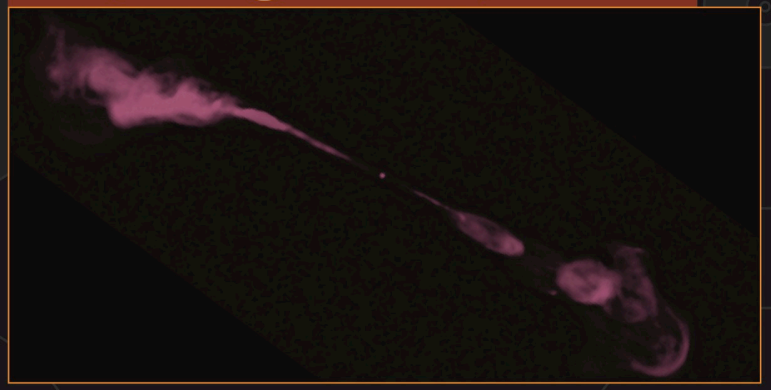
Perseus cluster of galaxies; MLGM/JHL/MPL

The four antenna configurations of the Karl G. Jansky Very Large Array (VLA) work together to reveal the jets emerging from galaxy Hercules A. Compact antenna spacings provide maximum sensitivity to diffuse clouds. Wide spacings provide the resolving power needed to see fine details. Combined, they yield a complete picture.

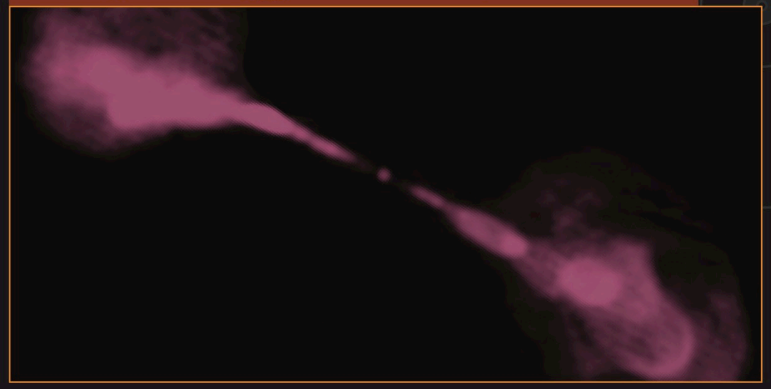
Configuration A : 22 mile array diameter



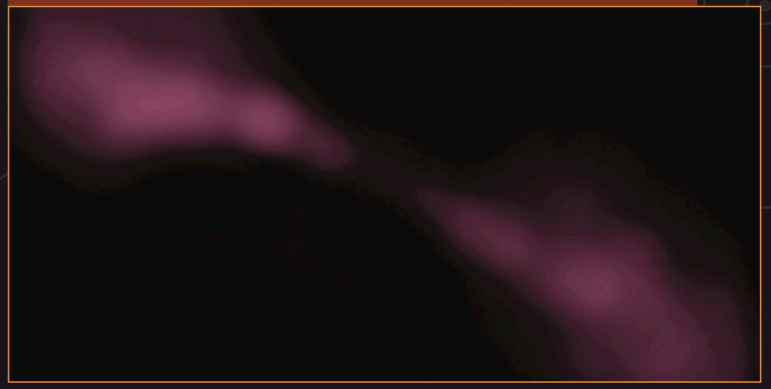
Configuration B : 7 mile array diameter



Configuration C : 2 mile array diameter



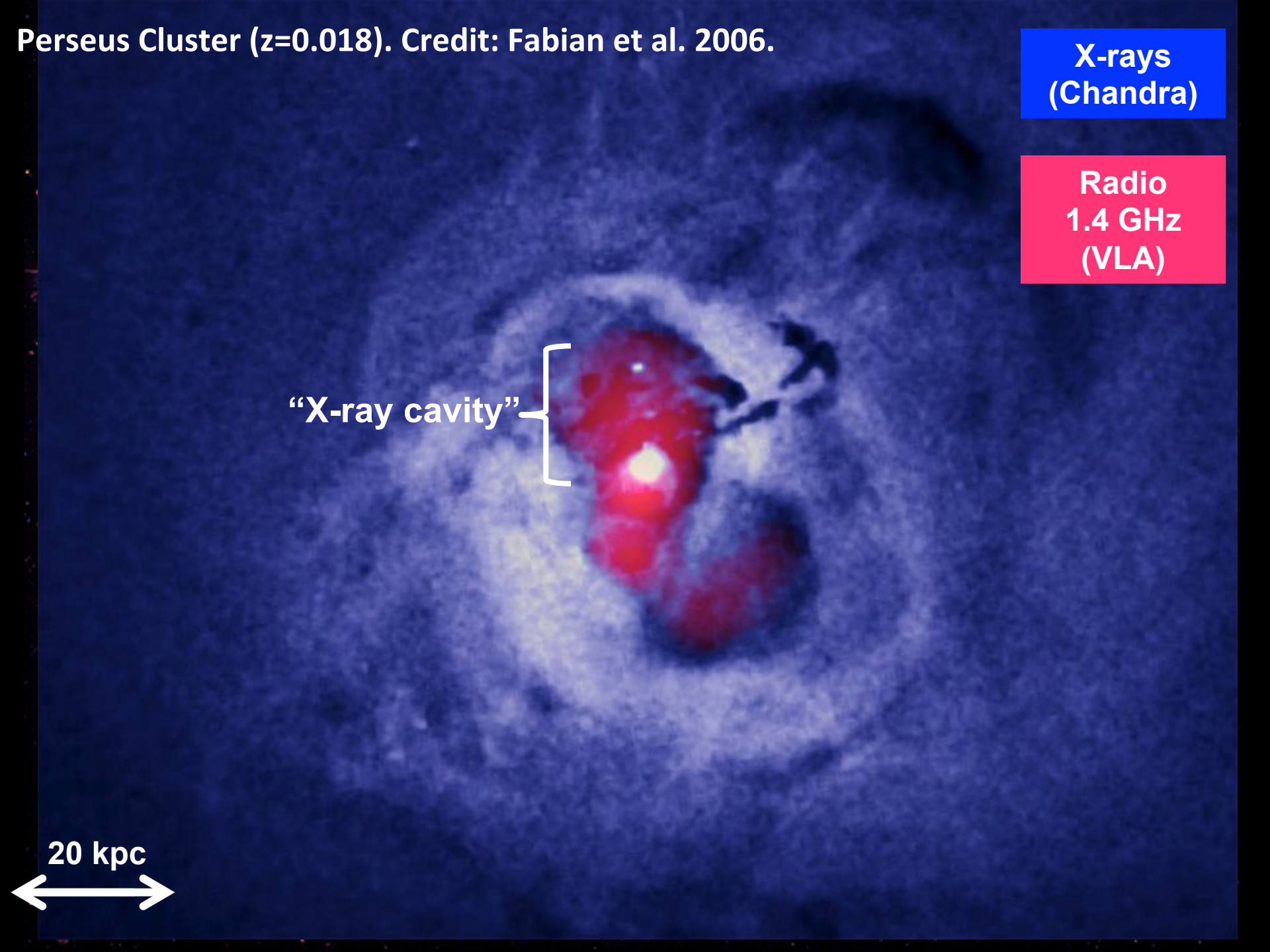
Configuration D : 0.6 mile array diameter

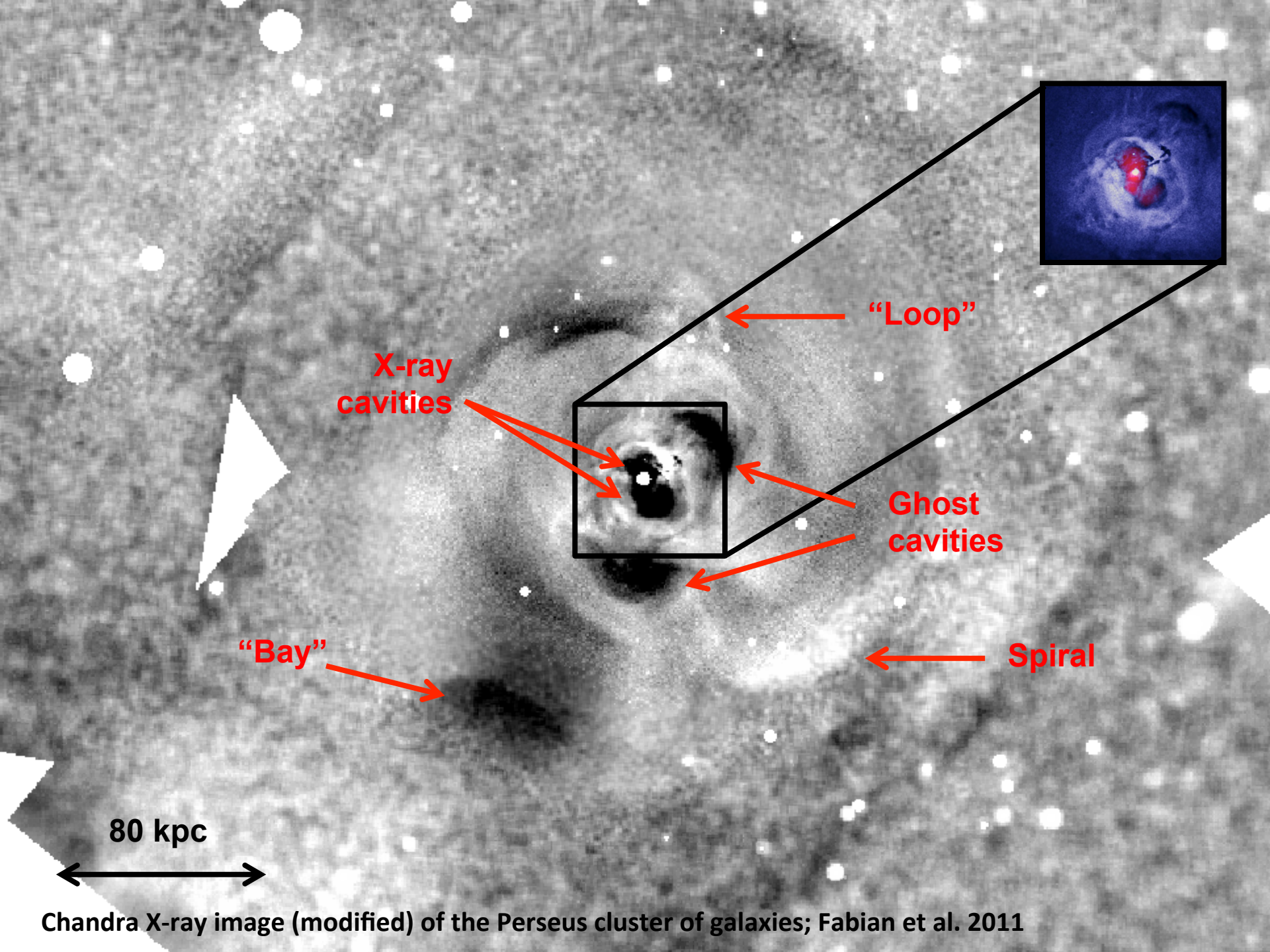


Credit: Hercules A, *NASA, ESA, S. Baum and C. O'Dea (RIT), R. Perley and W. Cotton (NRAO/AUI/NSF), and the Hubble Heritage Team (STScI/AURA)*

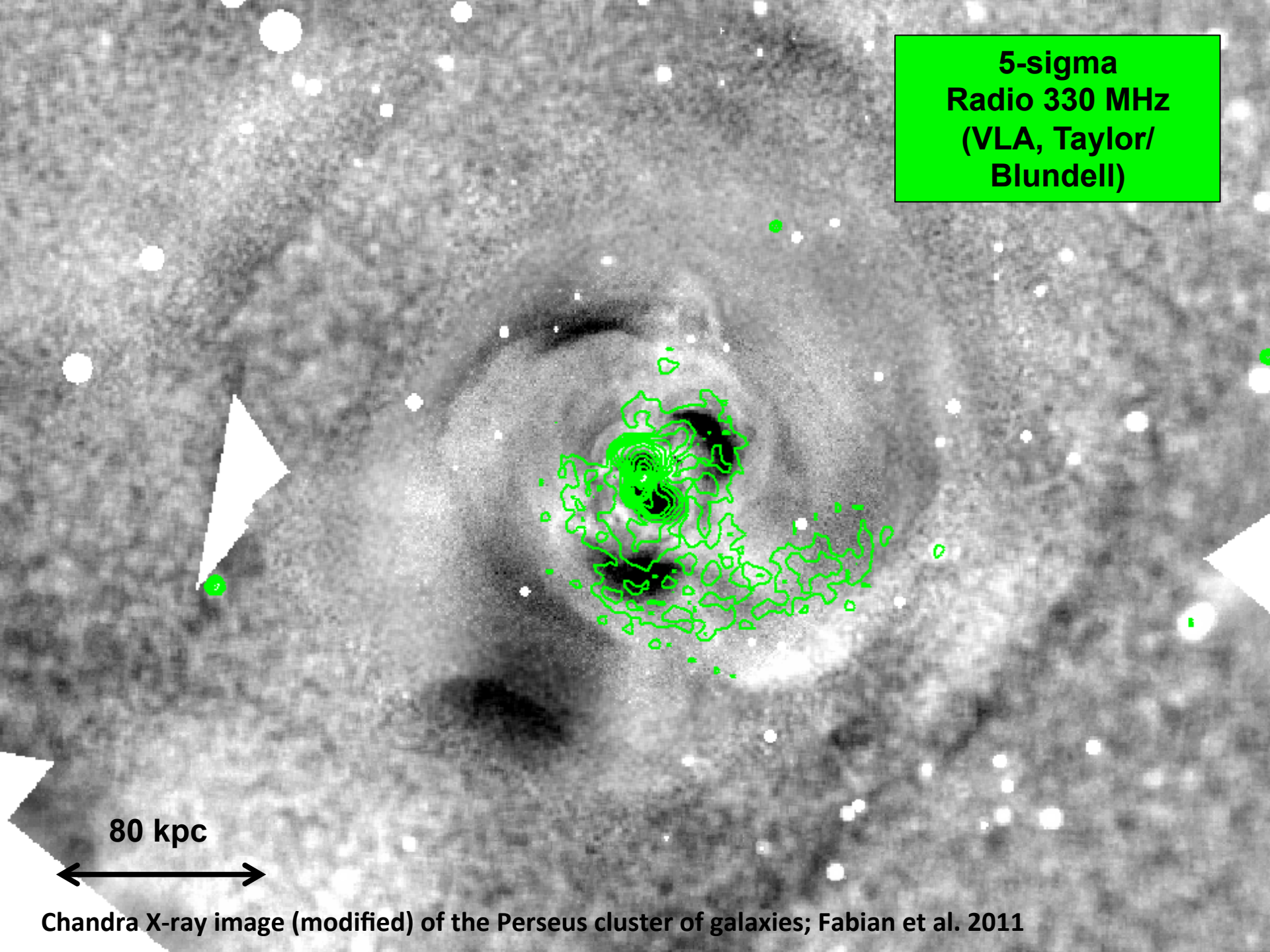
New JVLA (radio) Observations of Clusters of Galaxies

(AGN Feedback in high-z SPT clusters)


Perseus Cluster (z=0.018). Credit: Fabian et al. 2006.
X-rays (Chandra)
Radio 1.4 GHz (VLA)
"X-ray cavity"
20 kpc



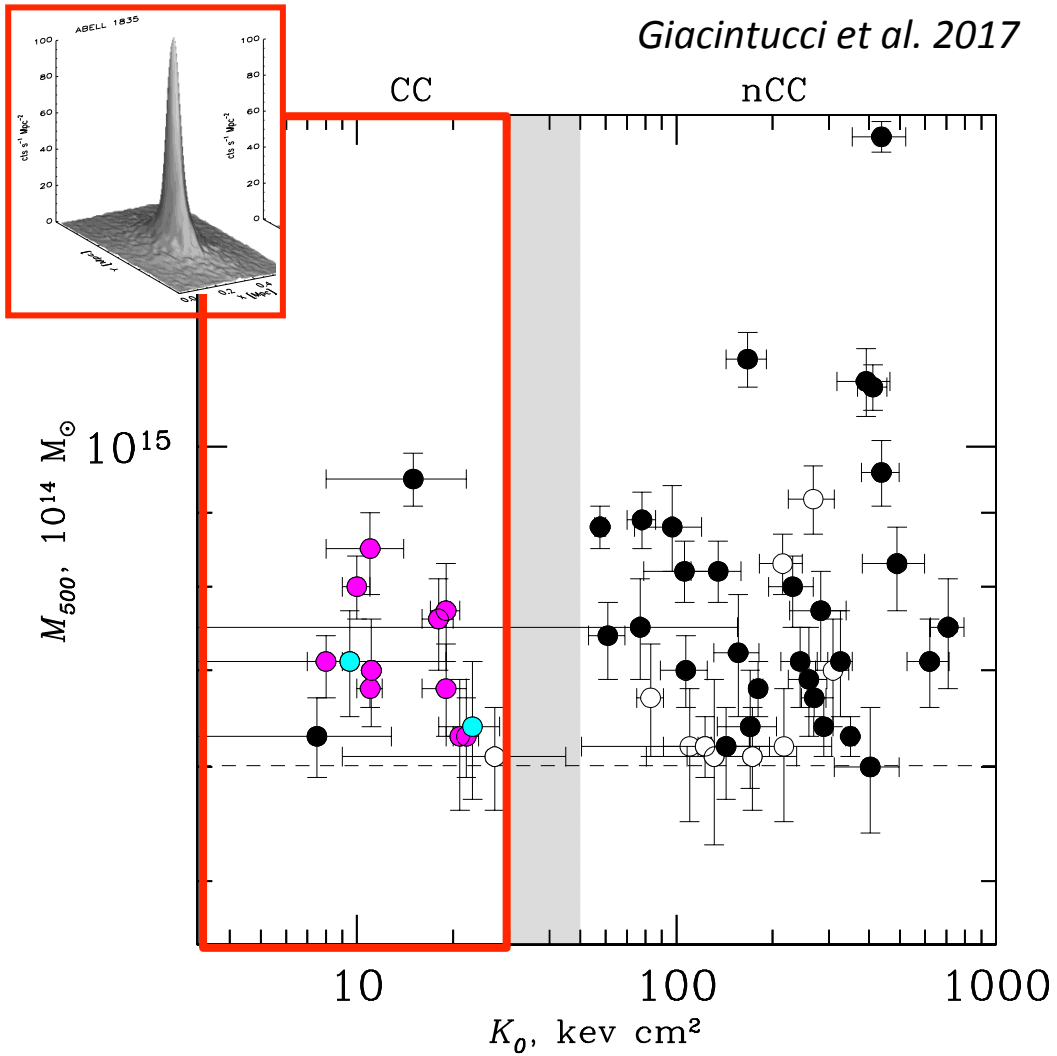
Chandra X-ray image (modified) of the Perseus cluster of galaxies; Fabian et al. 2011



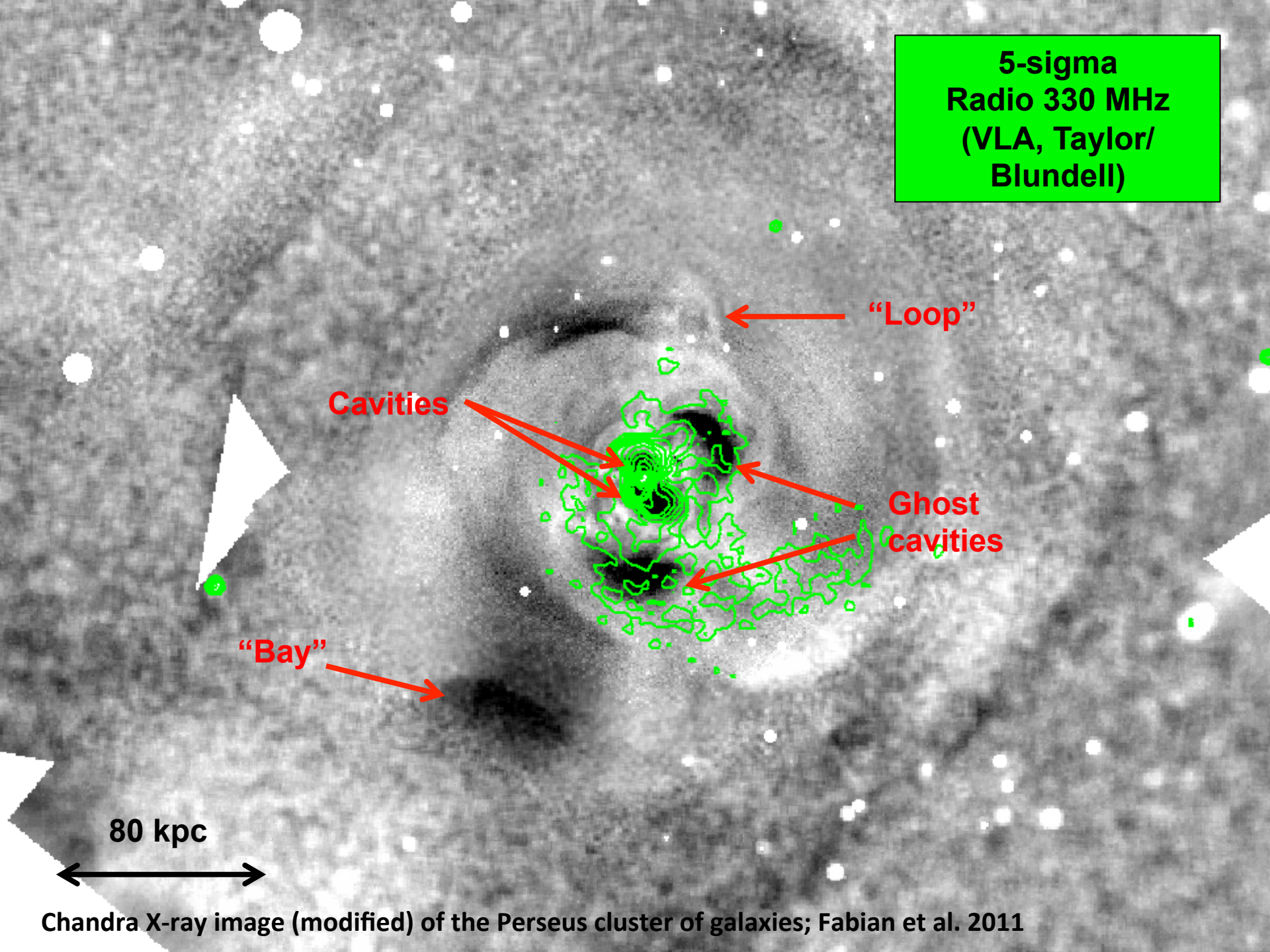
Chandra X-ray image (modified) of the Perseus cluster of galaxies; Fabian et al. 2011

Radio Mini-Halos in Cool Core Clusters

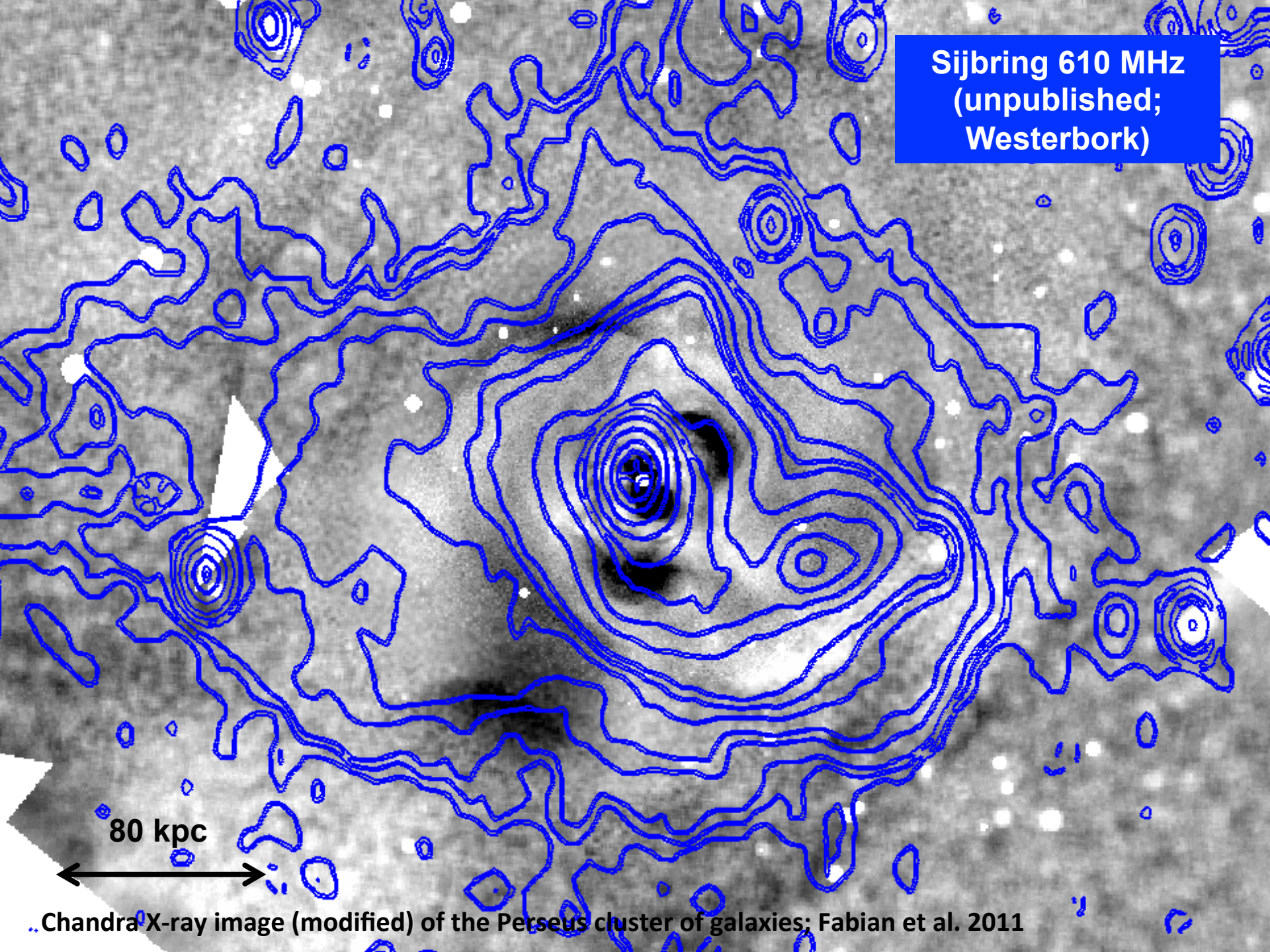
Cool Core cluster



- **Often bounded by cold fronts (e.g. Mazzotta & Giacintucci 2008): could sloshing-induced turbulence reaccelerate the electrons?**
- **Found in (all?) massive cool core clusters (e.g. Giacintucci et al. 2017): could AGN-driven turbulence reaccelerate the electrons?**
- **Freshly produced electrons from p-p collisions (e.g. Brunetti & Jones 2014).**



Chandra X-ray image (modified) of the Perseus cluster of galaxies; Fabian et al. 2011

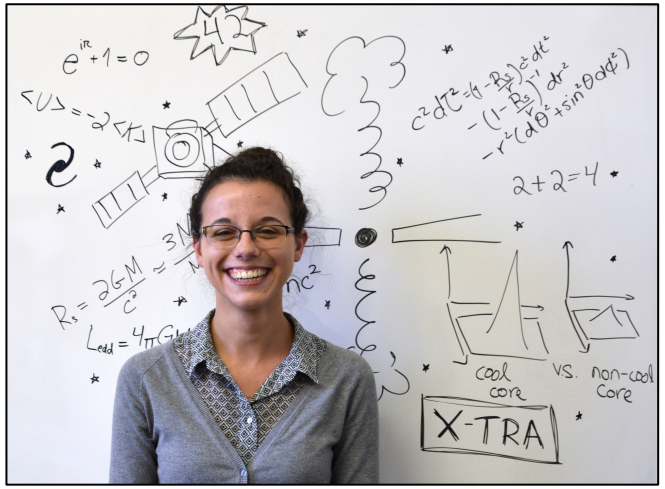


Chandra X-ray image (modified) of the Perseus cluster of galaxies; Fabian et al. 2011

Jansky Very Large Array (JVLA)

Shared-risk proposal (2013, PI Hlavacek-L.):

- P-band (270-430 MHz)
- 5 hours in B-config + A-config.
- > 5 times better resolution compared to Sijbring (unpublished results)



Marie-Lou Gendron-Marsolais

Challenges:

- Large datasets (Tbs) = computing time.
- P-band (270-430 MHz) = RFI.
- Shared-risk proposal = prototype problems, e.g. an entire arm was affected.

- Central AGN is 11 Jy bright = dynamic range limited.

B-Configuration Results:

See Poster!

ArXiv 1701.03791

MNRAS **469,** 3872–3880 (2017) doi: x1042

Deep 230–470 MHz VLA observations of the mini-halo in the Perseus cluster

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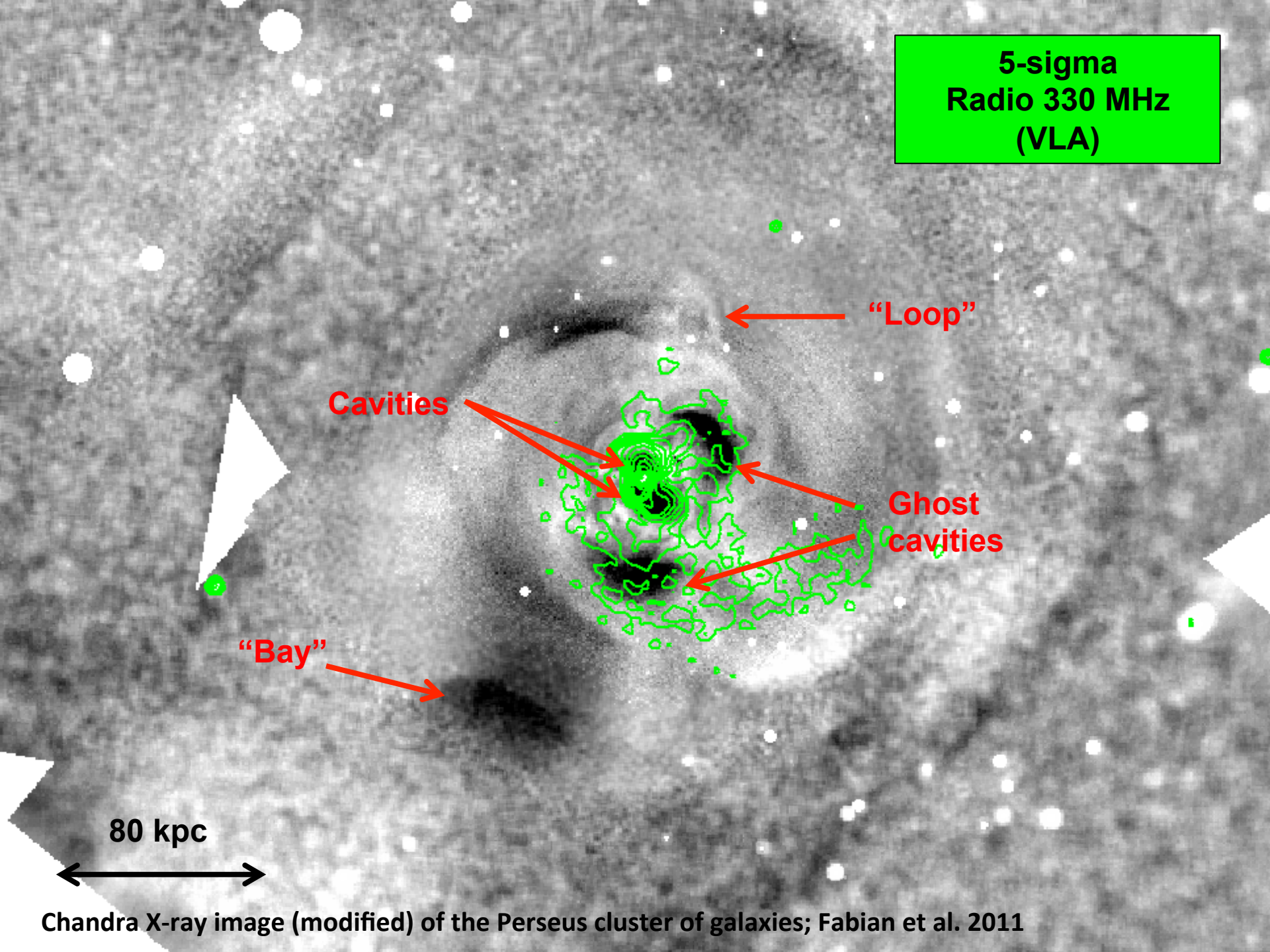
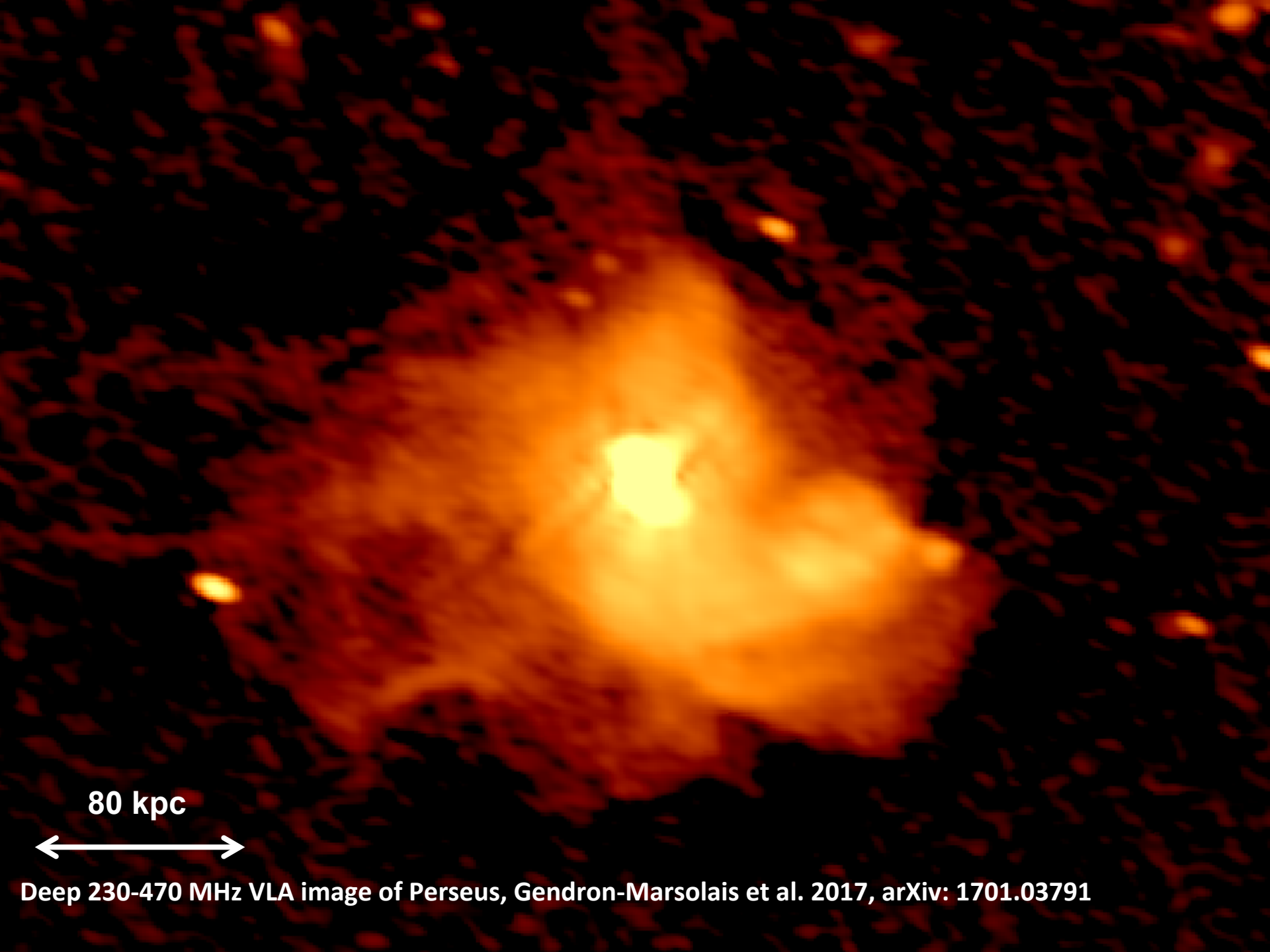
rms = 0.35 mJy/beam;
beam = 22.1″ × 11.3″ (8 kpc x 4 kpc);
Dynamic range > 30 000.

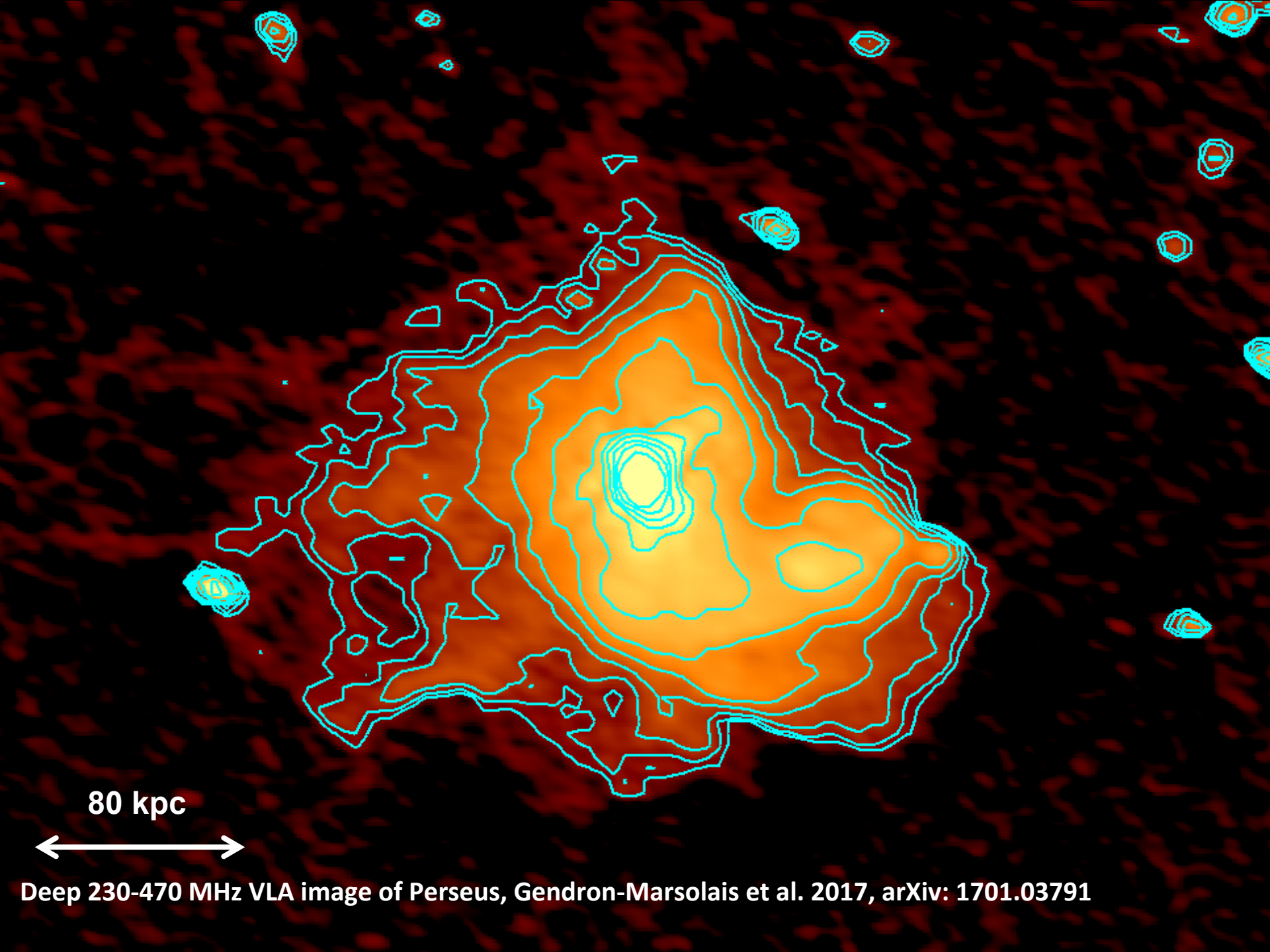
(NRAO press release: https://public.nrao.edu/news/galaxy-cluster-mini-halo/)



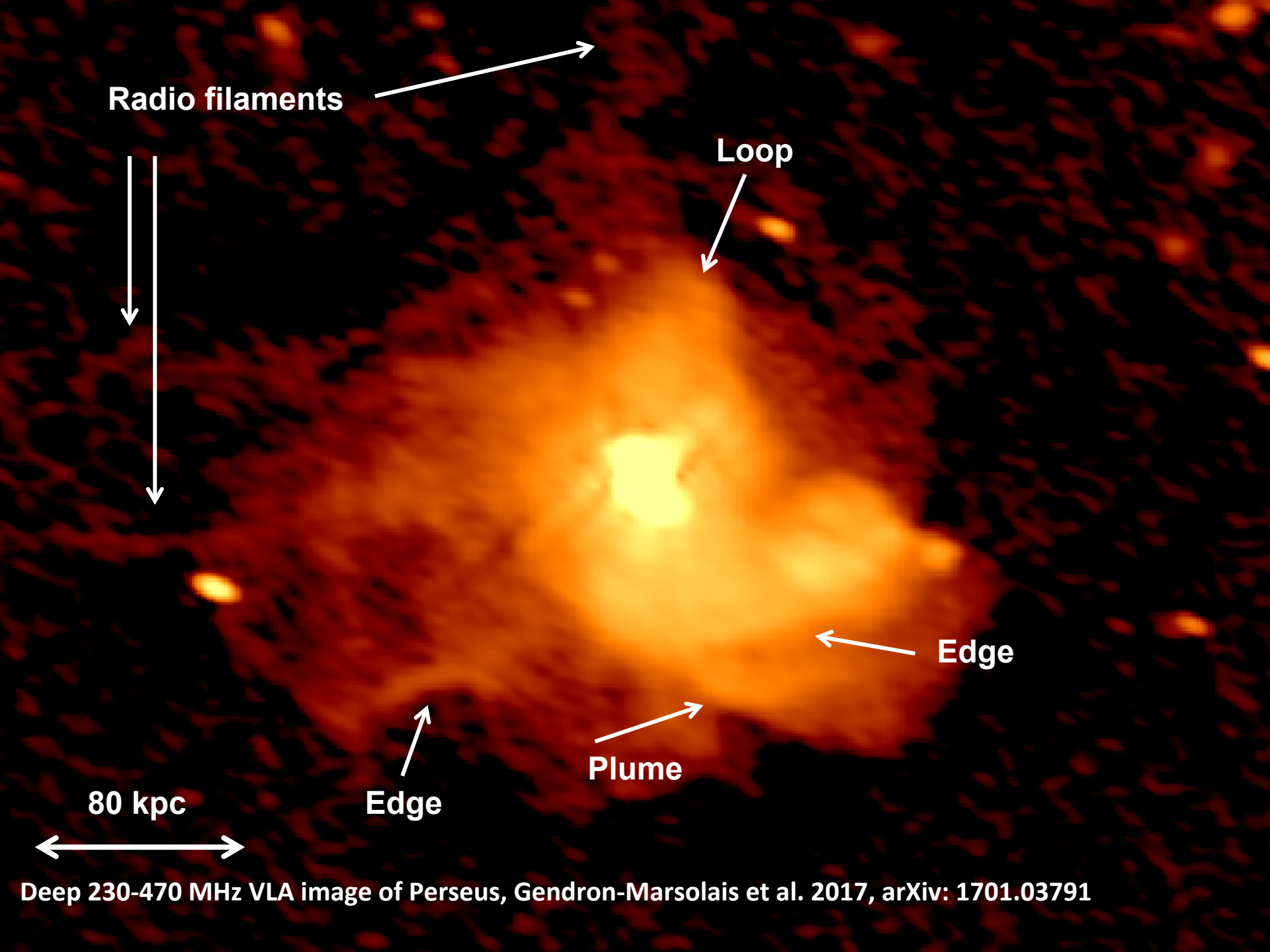
Chandra X-ray image (modified) of the Perseus cluster of galaxies; Fabian et al. 2011



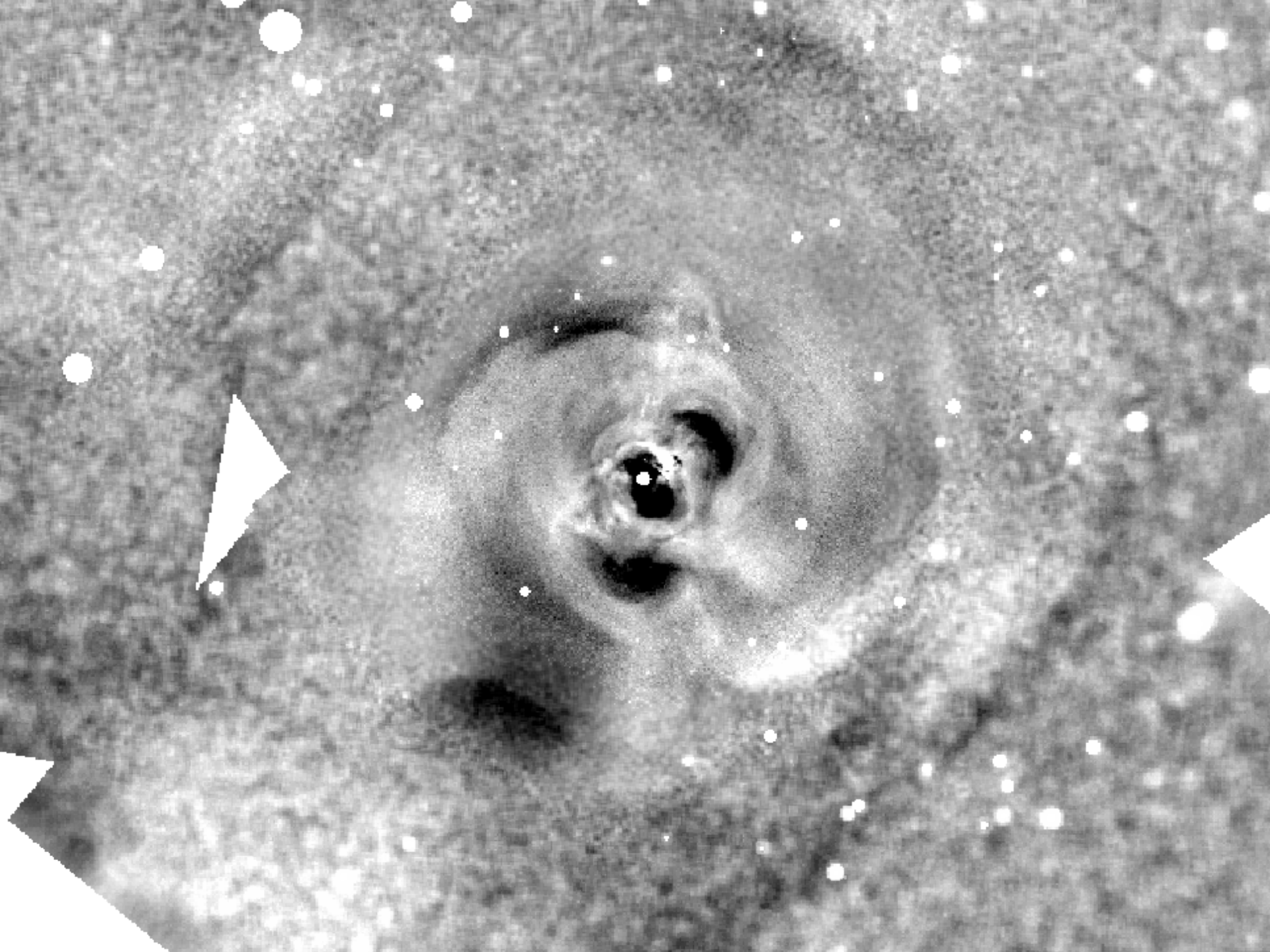
Deep 230-470 MHz VLA image of Perseus, Gendron-Marsolais et al. 2017, arXiv: 1701.03791

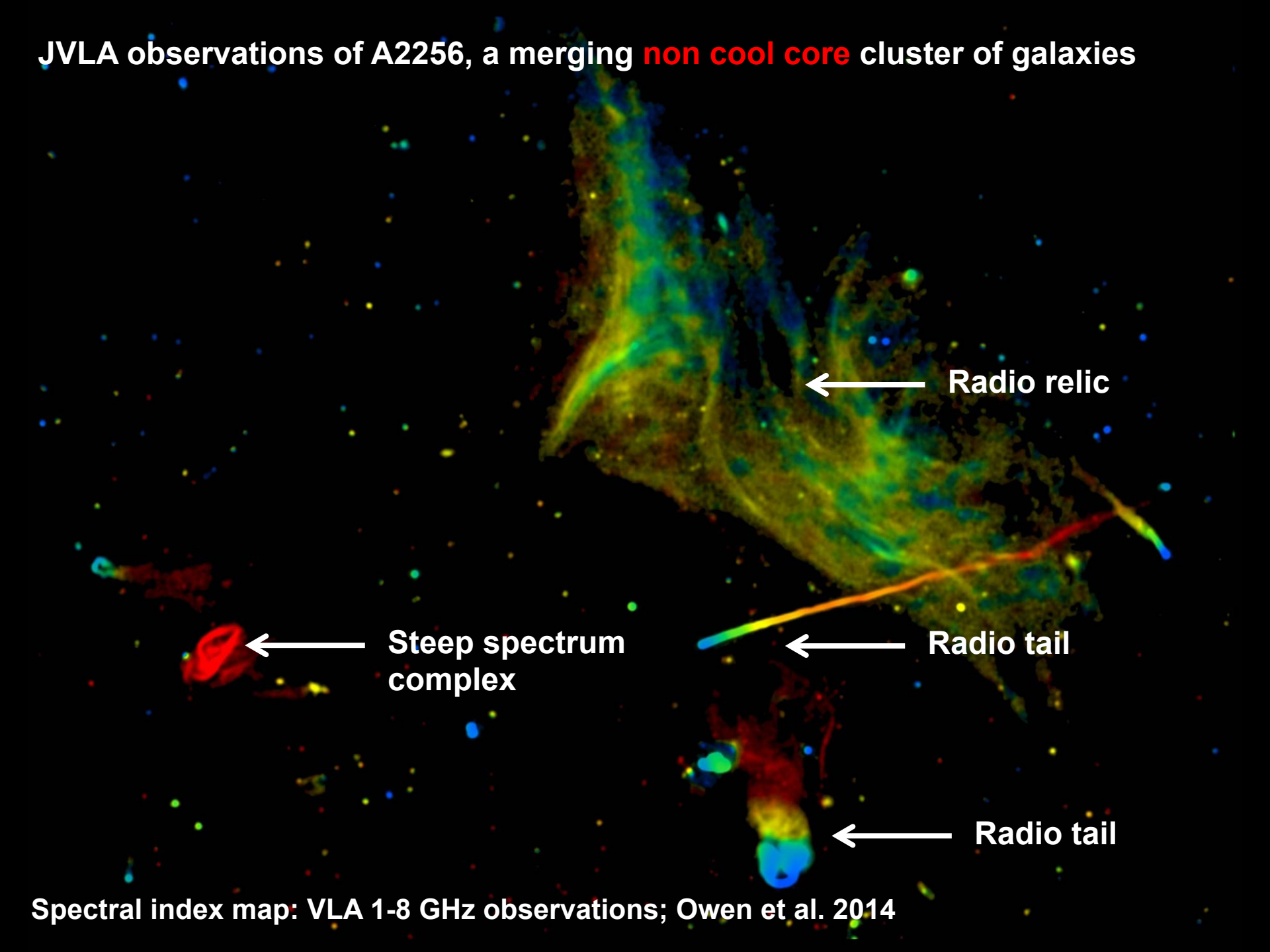


Deep 230-470 MHz VLA image of Perseus, Gendron-Marsolais et al. 2017, arXiv: 1701.03791

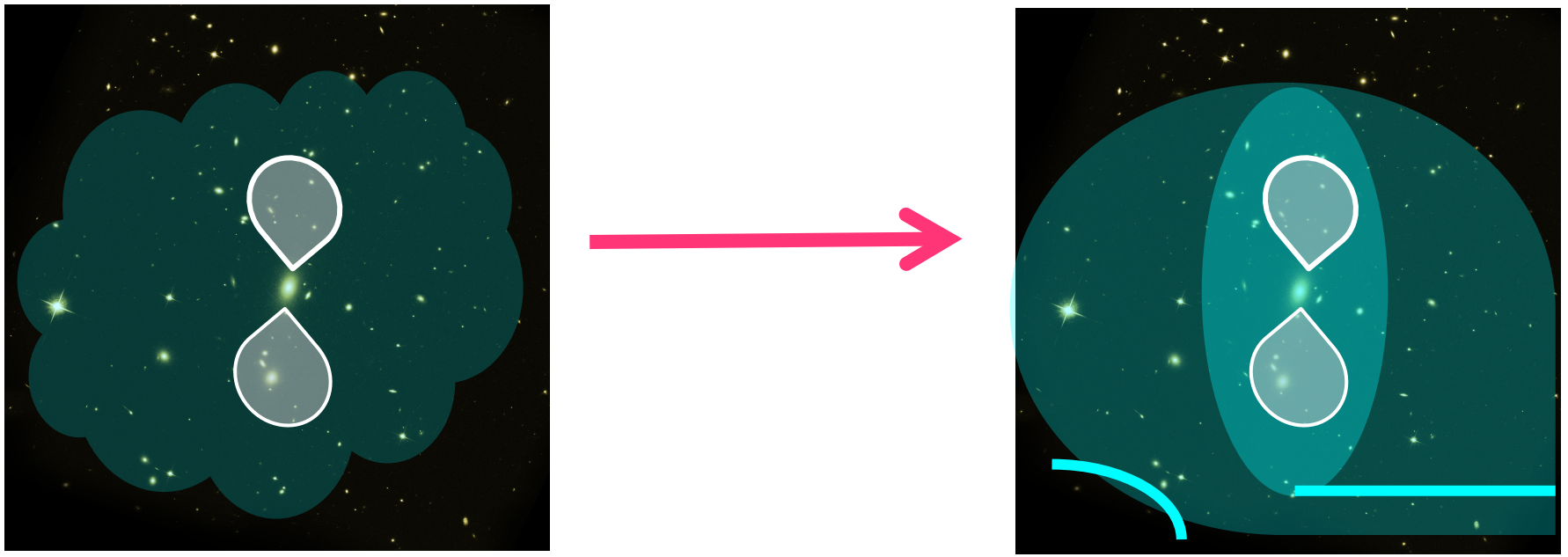


Deep 230-470 MHz VLA image of Perseus, Gendron-Marsolais et al. 2017, arXiv: 1701.03791




JVLA observations of A2256, a merging non cool core cluster of galaxies
Radio relic
Steep spectrum complex
Radio tail
Radio tail
Spectral index map: VLA 1-8 GHz observations; Owen et al. 2014

JVLA 230-470 MHz Observations of Perseus

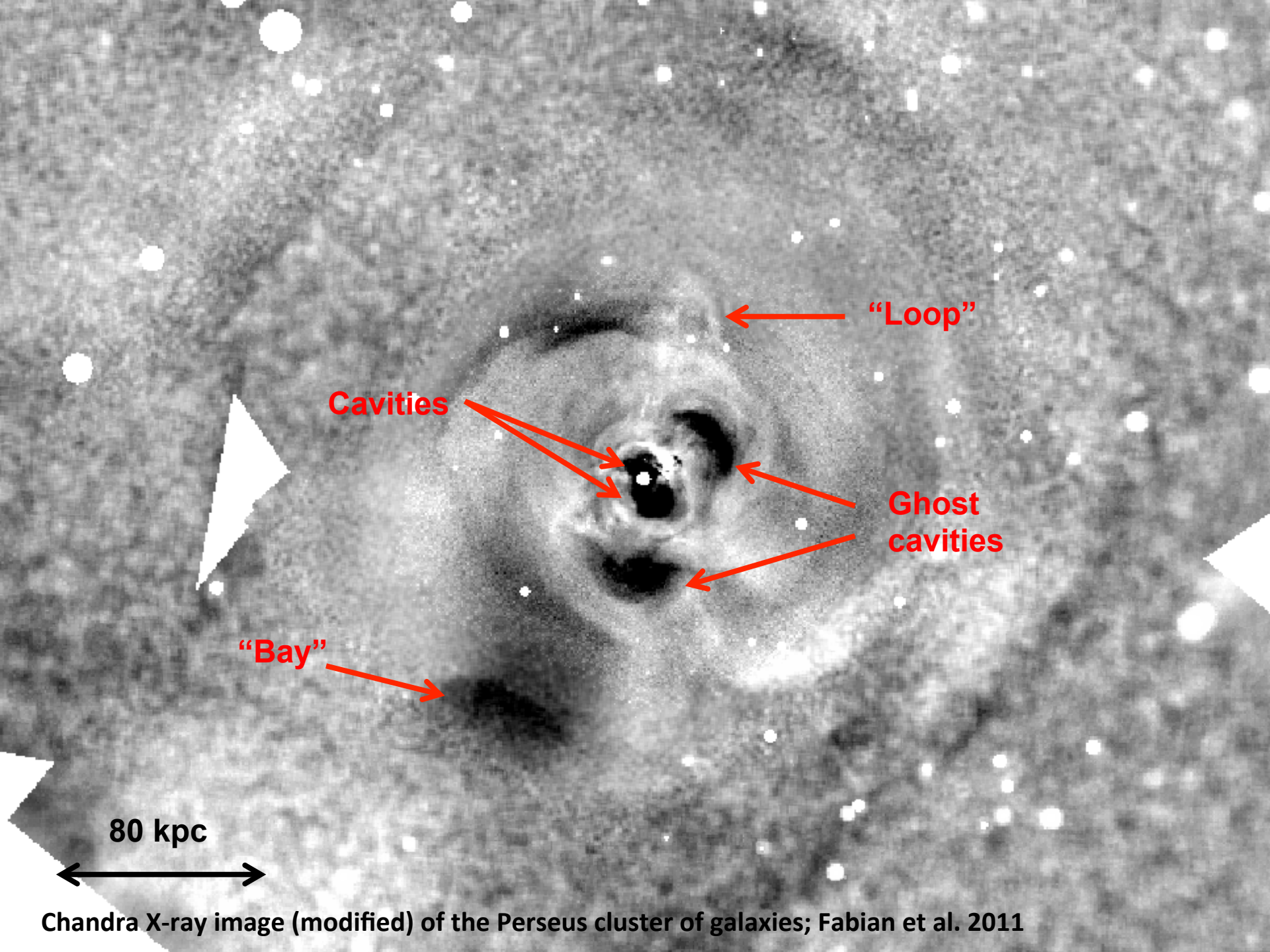


→ **Overall, this suggests that the reacceleration mechanism of the particles is connected to the sloshing motions (= turbulence due to mergers), but also to the BCG and its jets (= turbulence, sound waves?).**

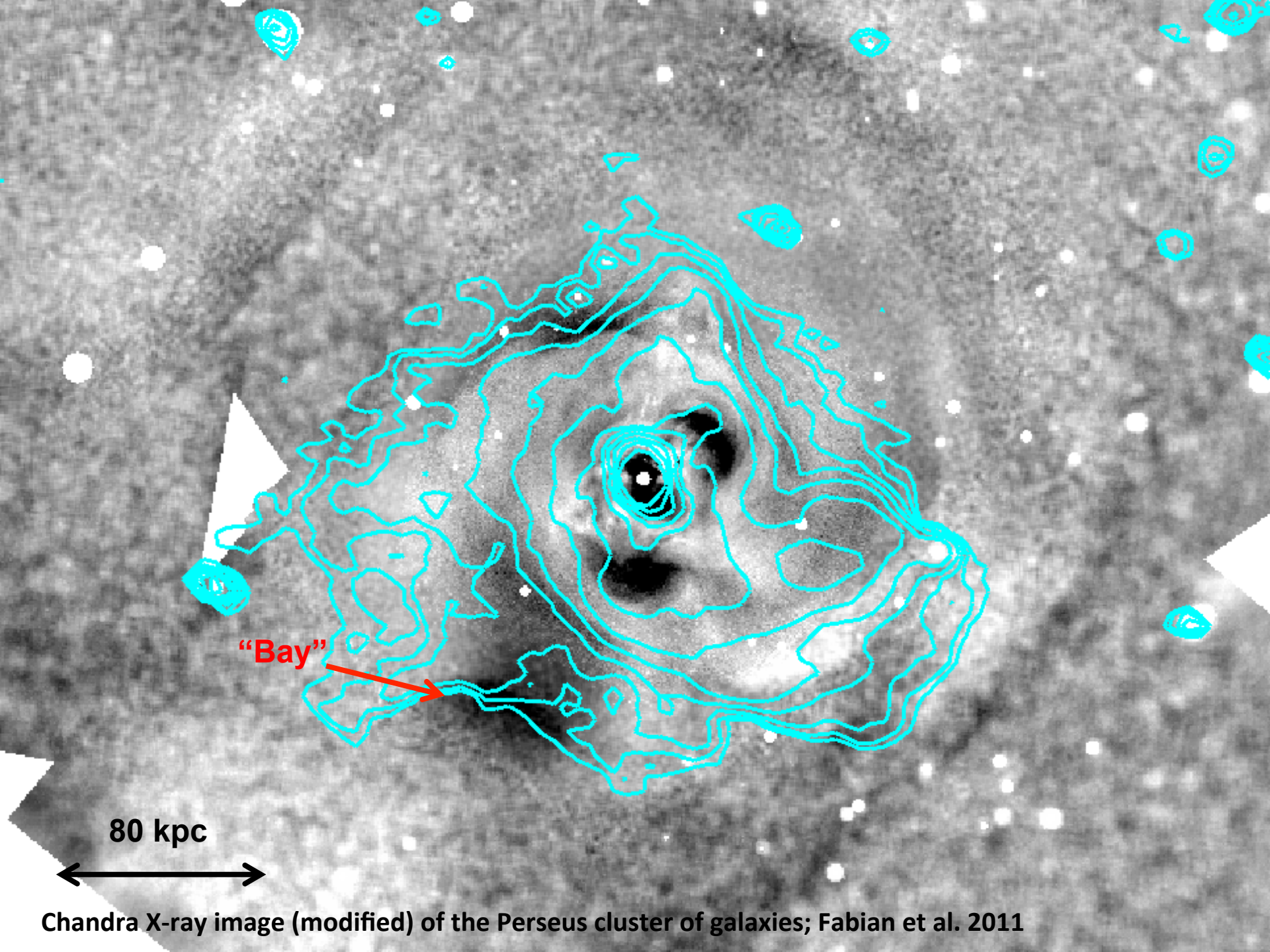
** Mysterious filamentary spurs of emission are found to the east and north, (like those in radio relics?), but no shocks are these radii are known.*

Gendron-Marsolais et al. 2017, arXiv: 1701.03791

Plasma Physics
in
Clusters of Galaxies



Chandra X-ray image (modified) of the Perseus cluster of galaxies; Fabian et al. 2011



Chandra X-ray image (modified) of the Perseus cluster of galaxies; Fabian et al. 2011

“Bays” in clusters of galaxies

ZuHone simulations

β = pressure $_{thermal}$ / pressure $_{non\text{-}thermal}$ = 200

Average magnetic field ~ 1-5 μG

→ “Bays” have been interpreted as old X-ray cavities.

→ However, they have strange curvature and lack radio emission. Also seen in A1795 and Centaurus cluster.

→ Instead, these “bays” could be giant **Kelvin-Helmholtz instabilities**.

Walker, Hlavacek-Larrondo et al. 2017, arXiv: 1705.00011

Julie Hlavacek-Larrondo, juliehl@astro.umontreal.ca

Take-Home Points

1) **Clusters are fantastic laboratories for studying AGN feedback:**

2) **Strong radio sources:**

   → **New JVLA observations of the Perseus cluster** reveal that mini-halos are not uniform, diffuse structures, but are instead composed of a rich variety of complex structures, including arcs, filaments and edges. See **Gendron-Marsolais et al. 2017, arXiv: 1701.03791.**

   → Mini-halos appear to be reaccelerated both by **sloshing motions of the hot intracluster medium** (= turbulence) and by mechanisms related to the **BCG and its jets** (= turbulence?).

3) **Plasma physics (giant Kelvin-Helmholtz instability in Perseus?)**

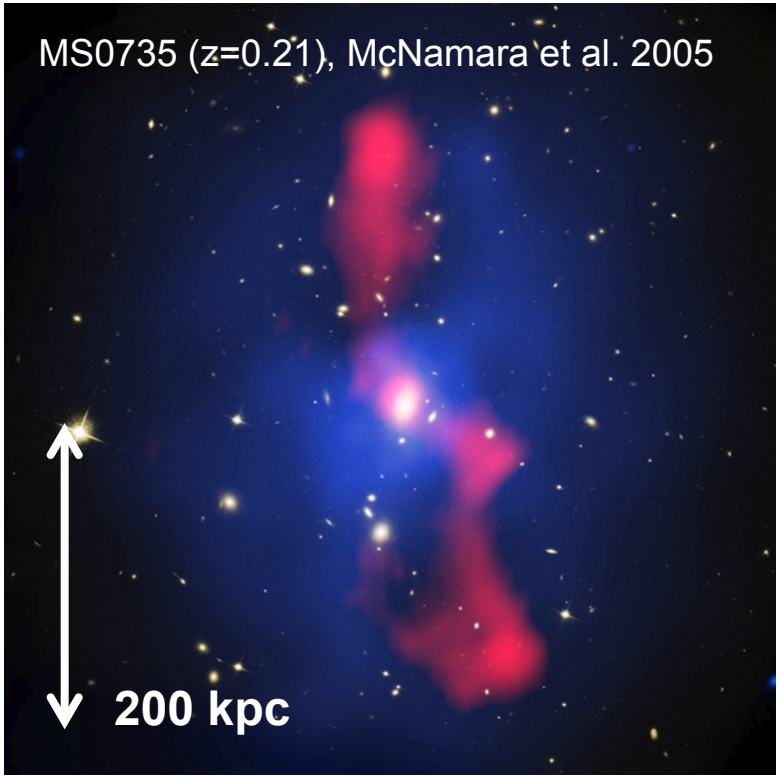
Fonds de recherche Nature et technologies Québec
NSERC CRSNG
Canada Research Chairs

BONUS:

The Evolution of AGN Feedback in Clusters of Galaxies

AGN Feedback in Clusters of Galaxies

z < 0.3

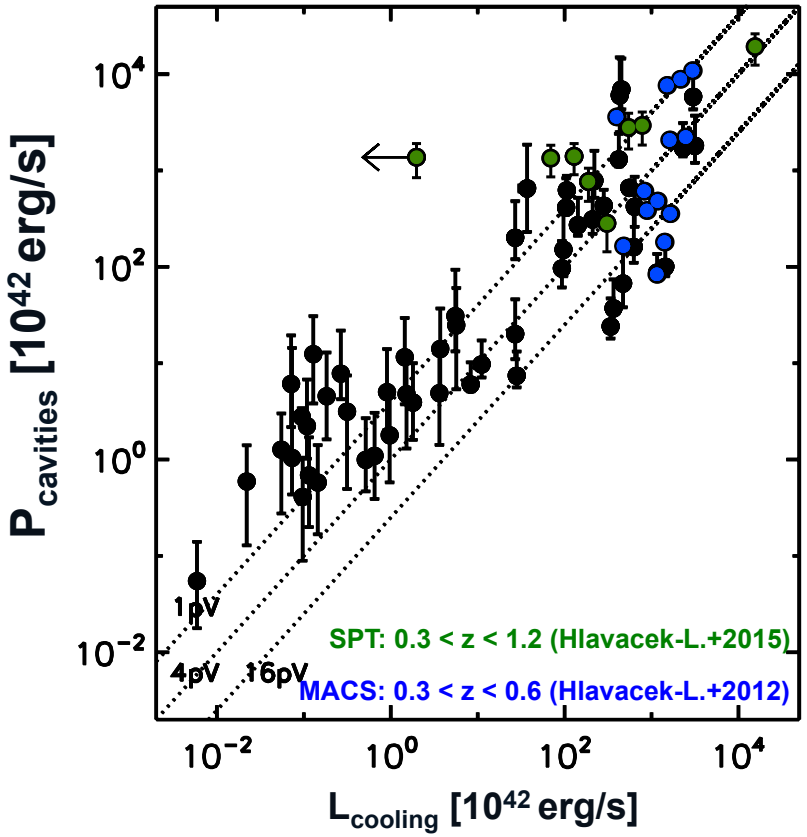


z > 0.3

?

The South Pole Telescope

AGN feedback in SPT Clusters of Galaxies



→ No significant evolution of mechanical AGN feedback for > 8 Gyrs.

Hlavacek-Larrondo et al. 2012a, 2015.

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