

The complexity of cluster turbulence: the filamentary radio halo in Abell 2319

Alexander Drabent

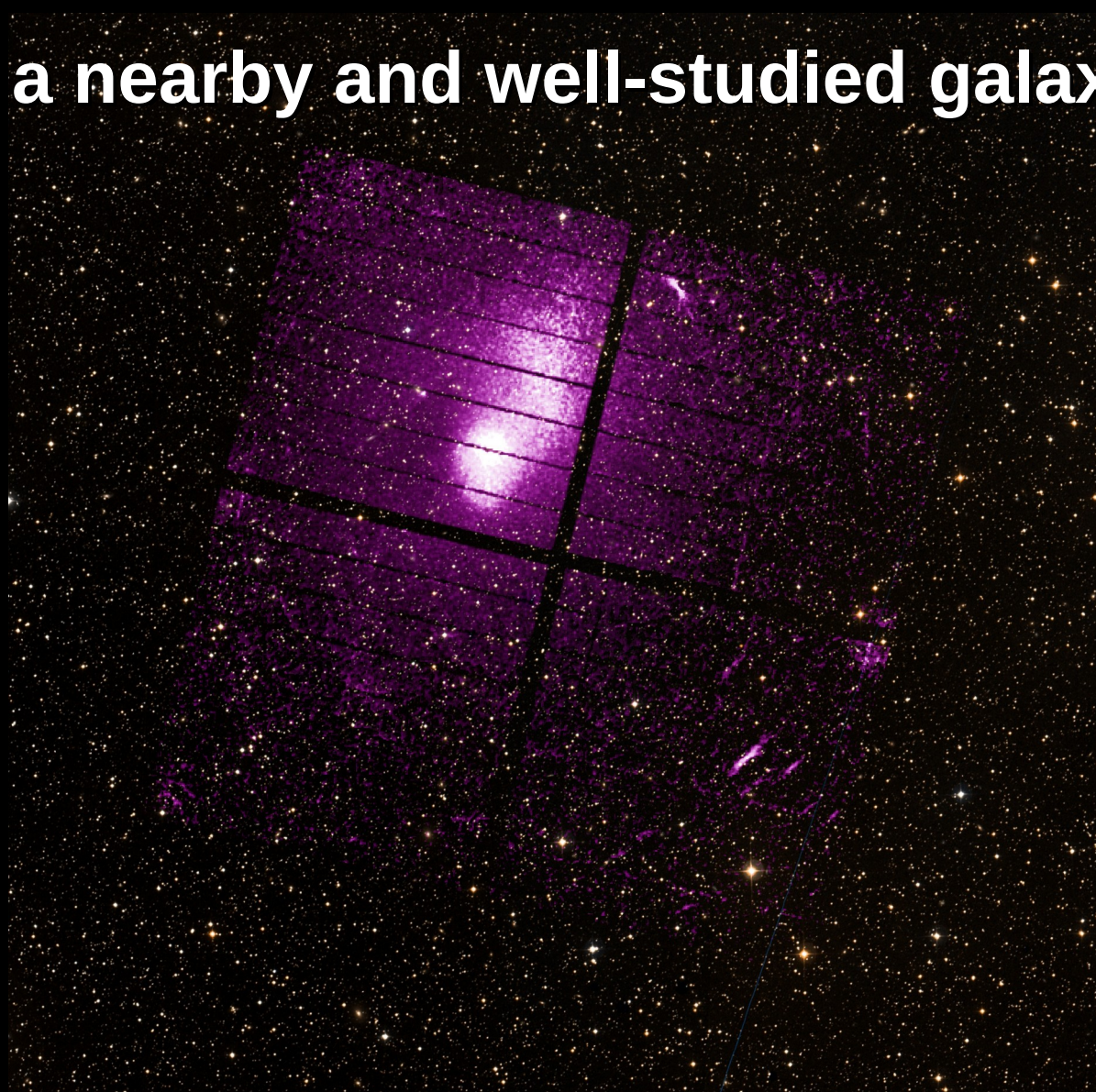
Thuringian State Observatory Tautenburg



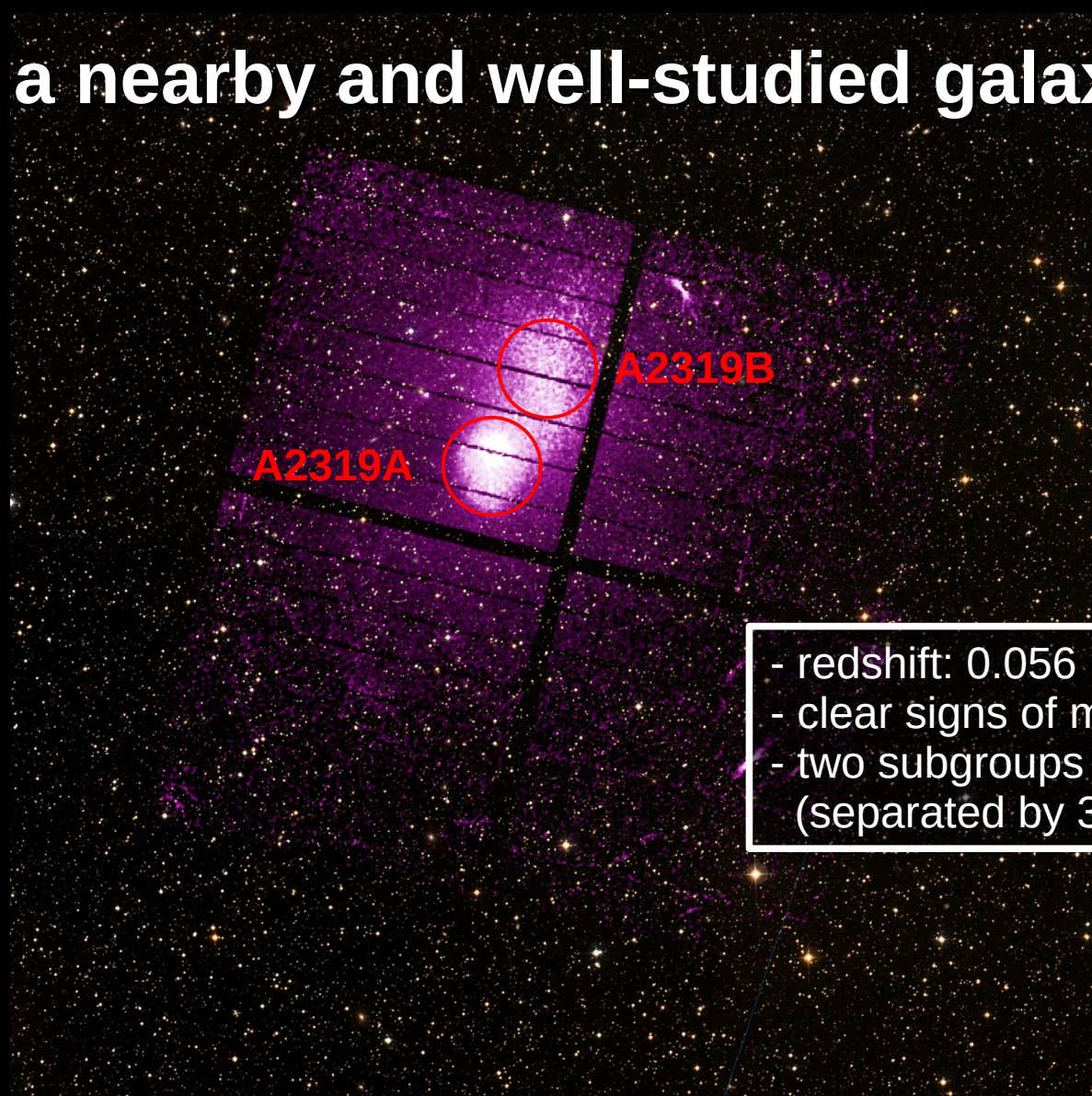
12th June 2026

LOFAR Annual Meeting 2026, Dublin, Ireland

Abell 2319: a nearby and well-studied galaxy cluster



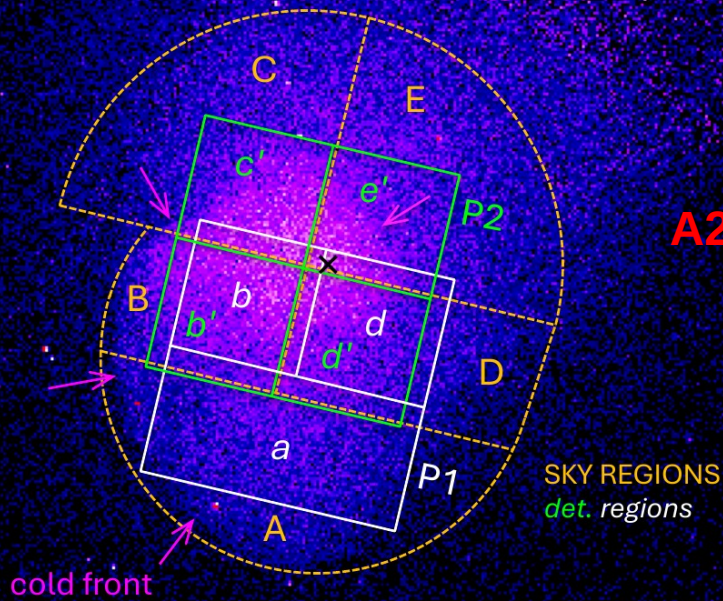
Abell 2319: a nearby and well-studied galaxy cluster



- redshift: 0.056
- clear signs of merger activity
- two subgroups in the line-of-sight (separated by 3000 km s^{-1})

Abell 2319: a nearby and well-studied galaxy cluster

Chandra ACIS image (0.5–4 keV)



A2319A

A2319B

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- two subgroups in the line-of-sight (separated by 3000 km s^{-1})

XRISM Collaboration 2025

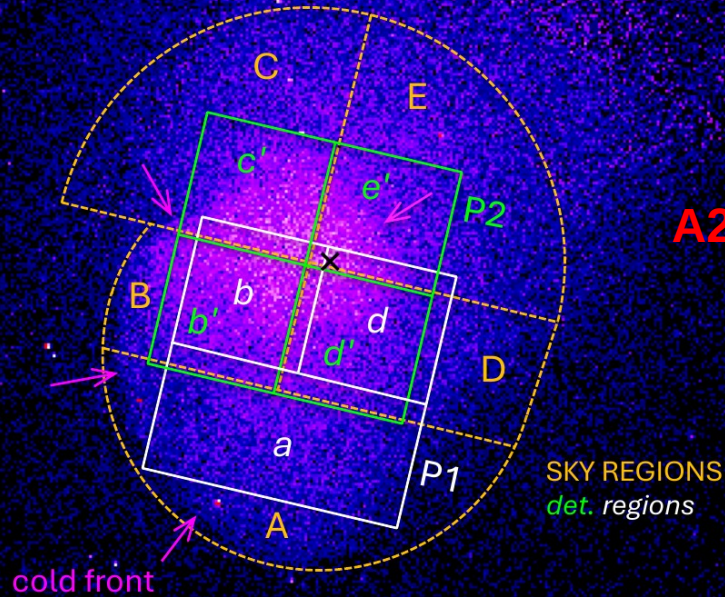


Credit: ESA

X-ray (XRISM), Optical (DSS)

Abell 2319: a nearby and well-studied galaxy cluster

Chandra ACIS image (0.5–4 keV)



A2319A

A2319B

100 kpc

Spiral structure

eroded by KHI

Ichinohe+2021

XRISM Collaboration 2025



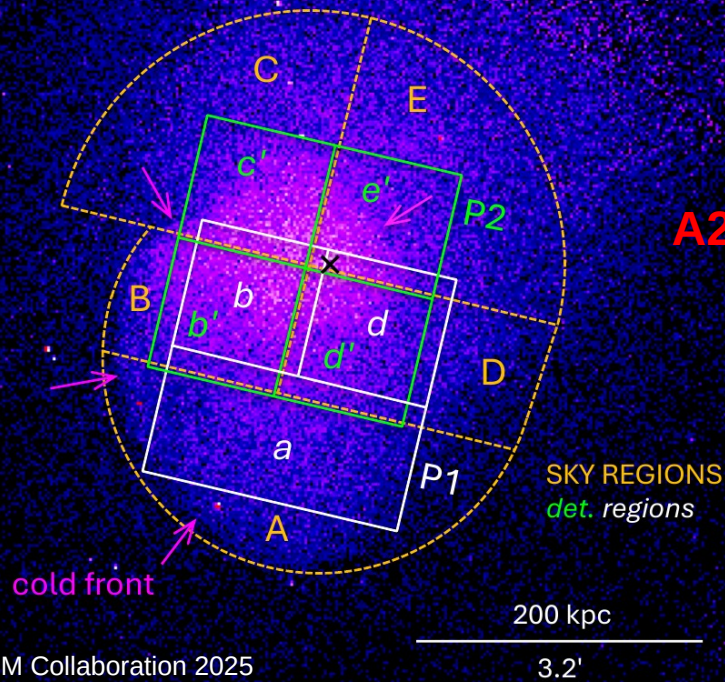
- one of the X-ray-brightest clusters
- average ICM temperature up to 8 keV
- prominent **cold front** in the center → gas sloshing?

Credit: ESA

X-ray (XRISM), Optical (DSS)

Abell 2319: a nearby and well-studied galaxy cluster

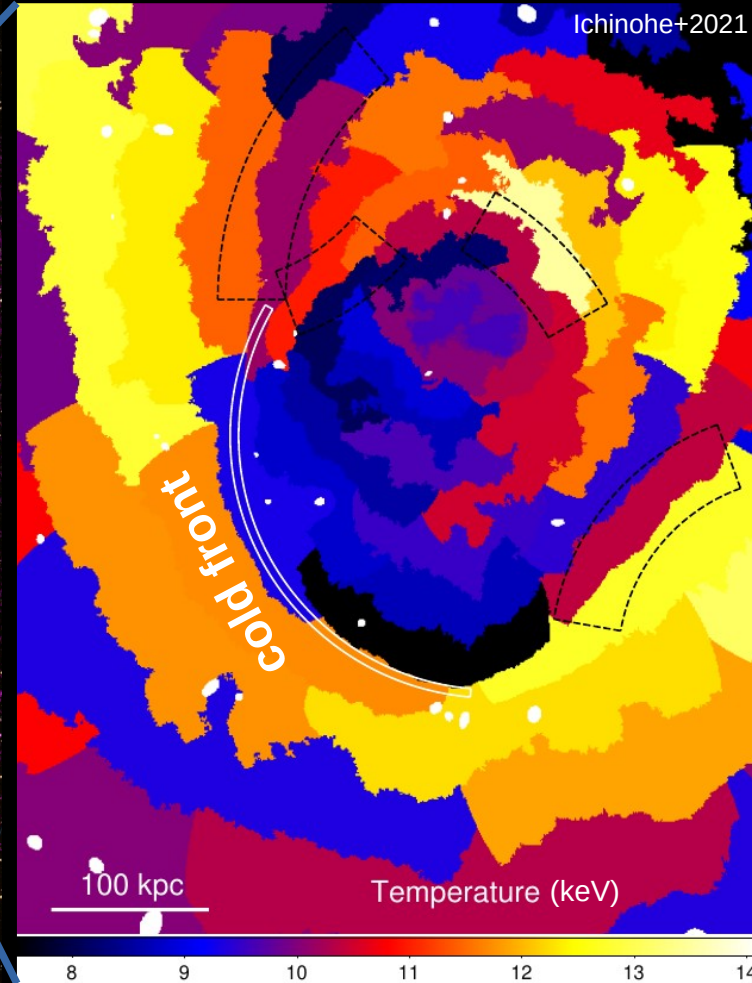
Chandra ACIS image (0.5–4 keV)



Ichinohe+2021

A2319A

A2319B



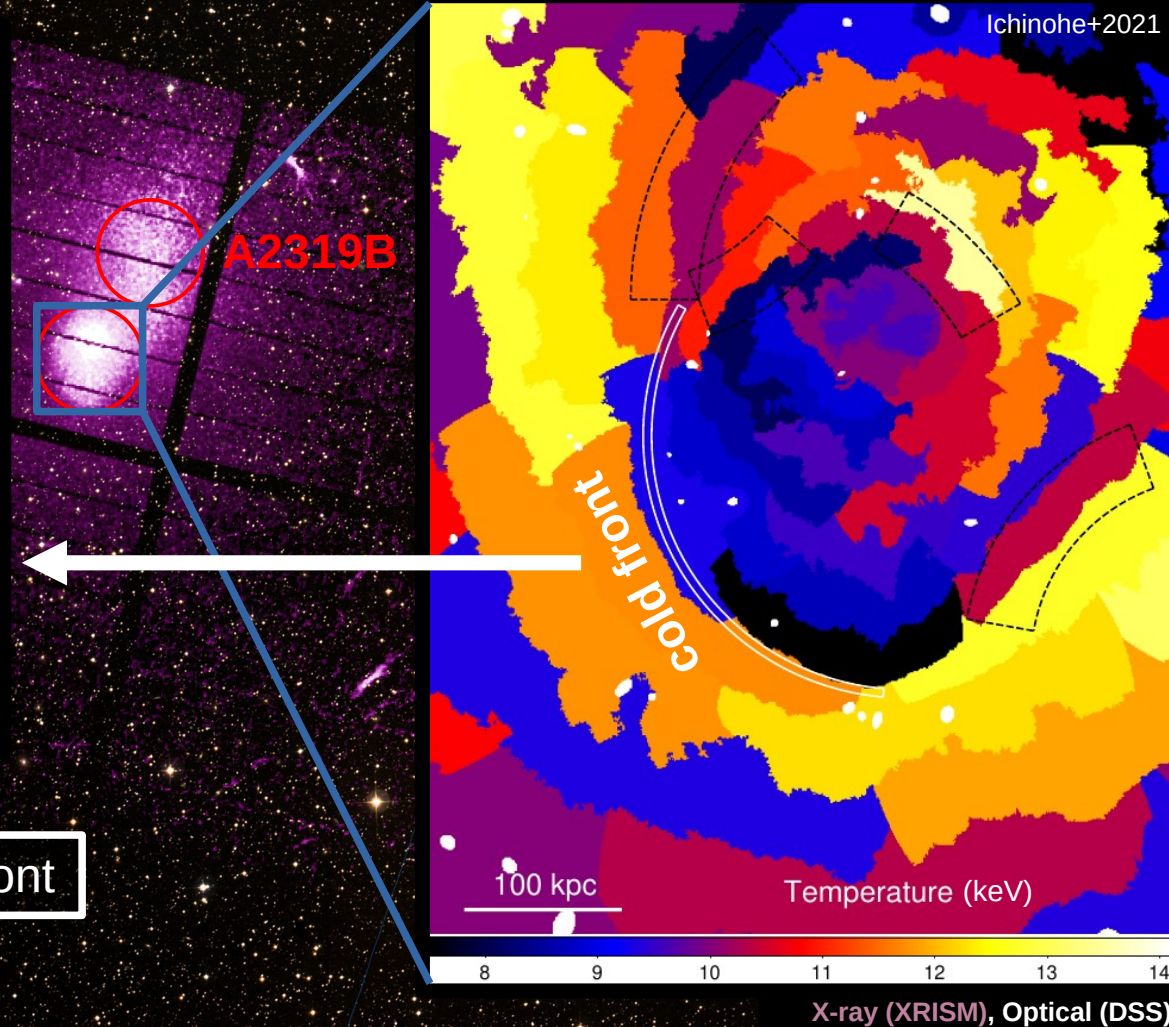
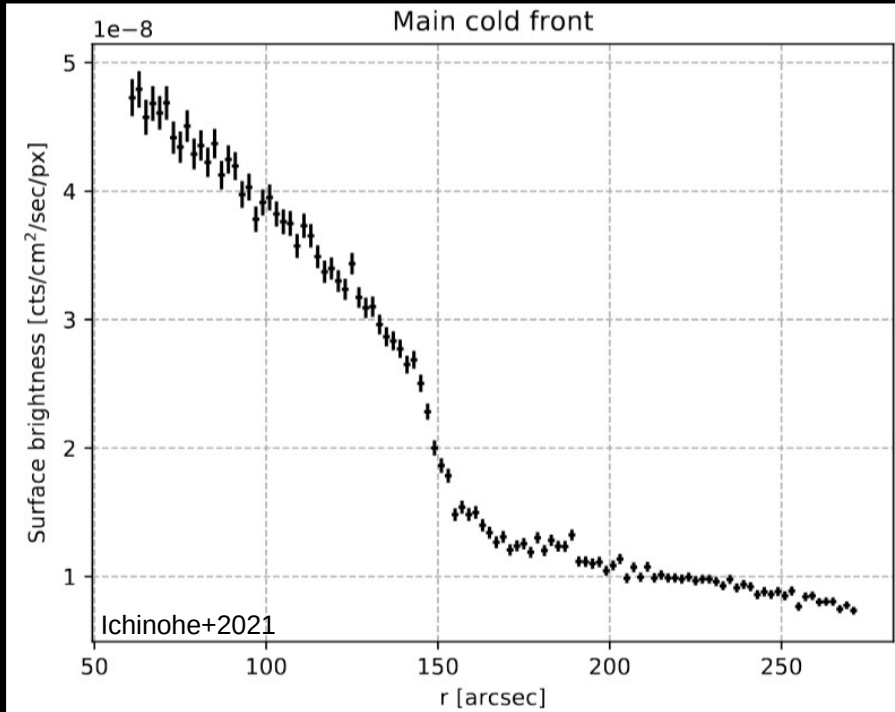
XRISM Collaboration 2025



- **complex** temperature distribution in the outskirts
- prominent **cool** core of A2319A

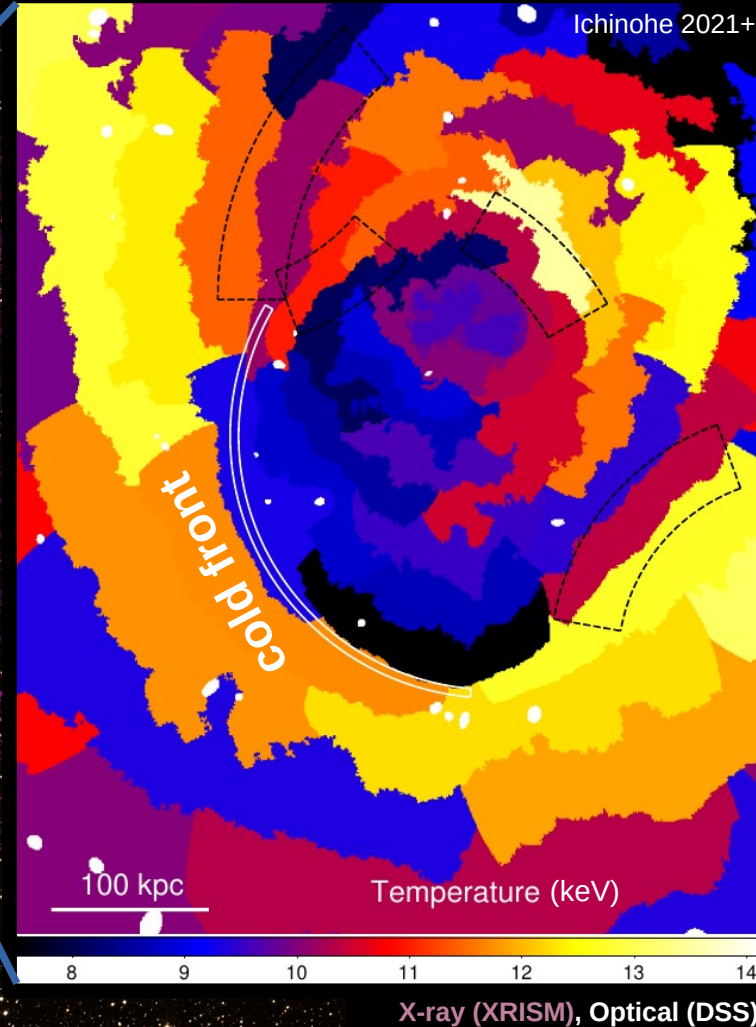
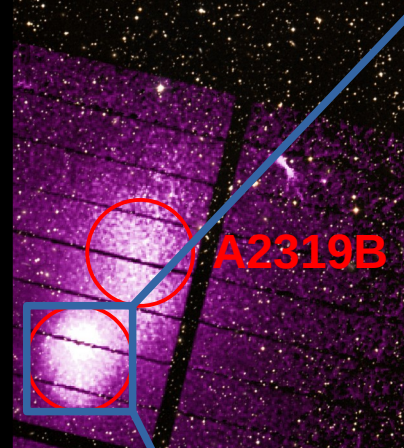
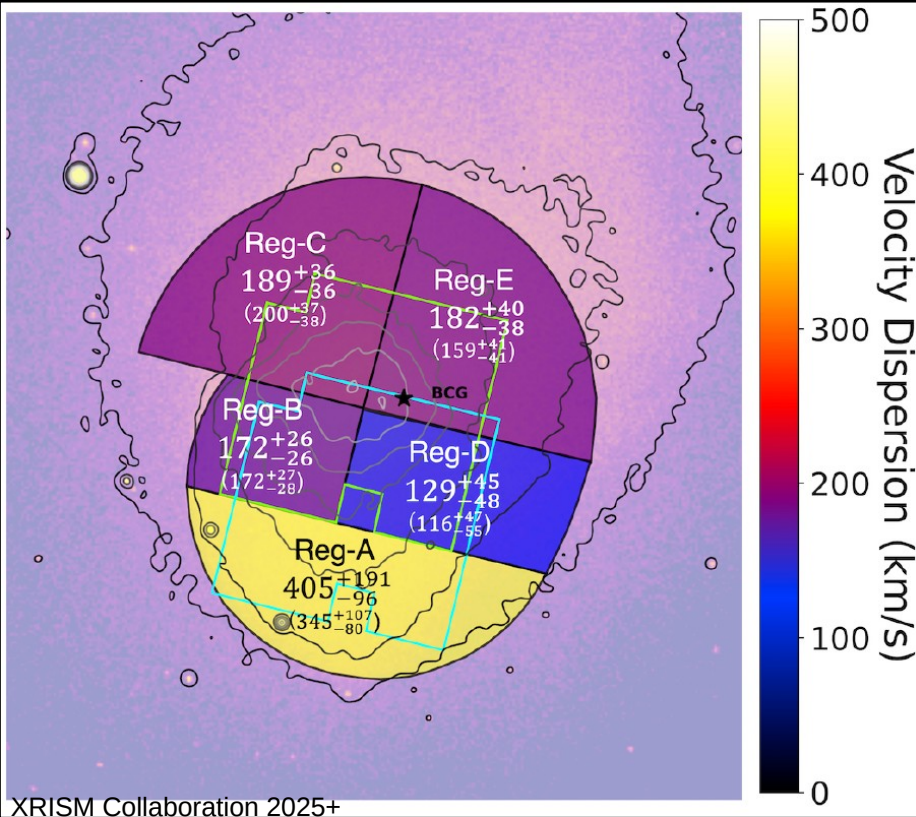
X-ray (XRISM), Optical (DSS)

Abell 2319: a nearby and well-studied galaxy cluster



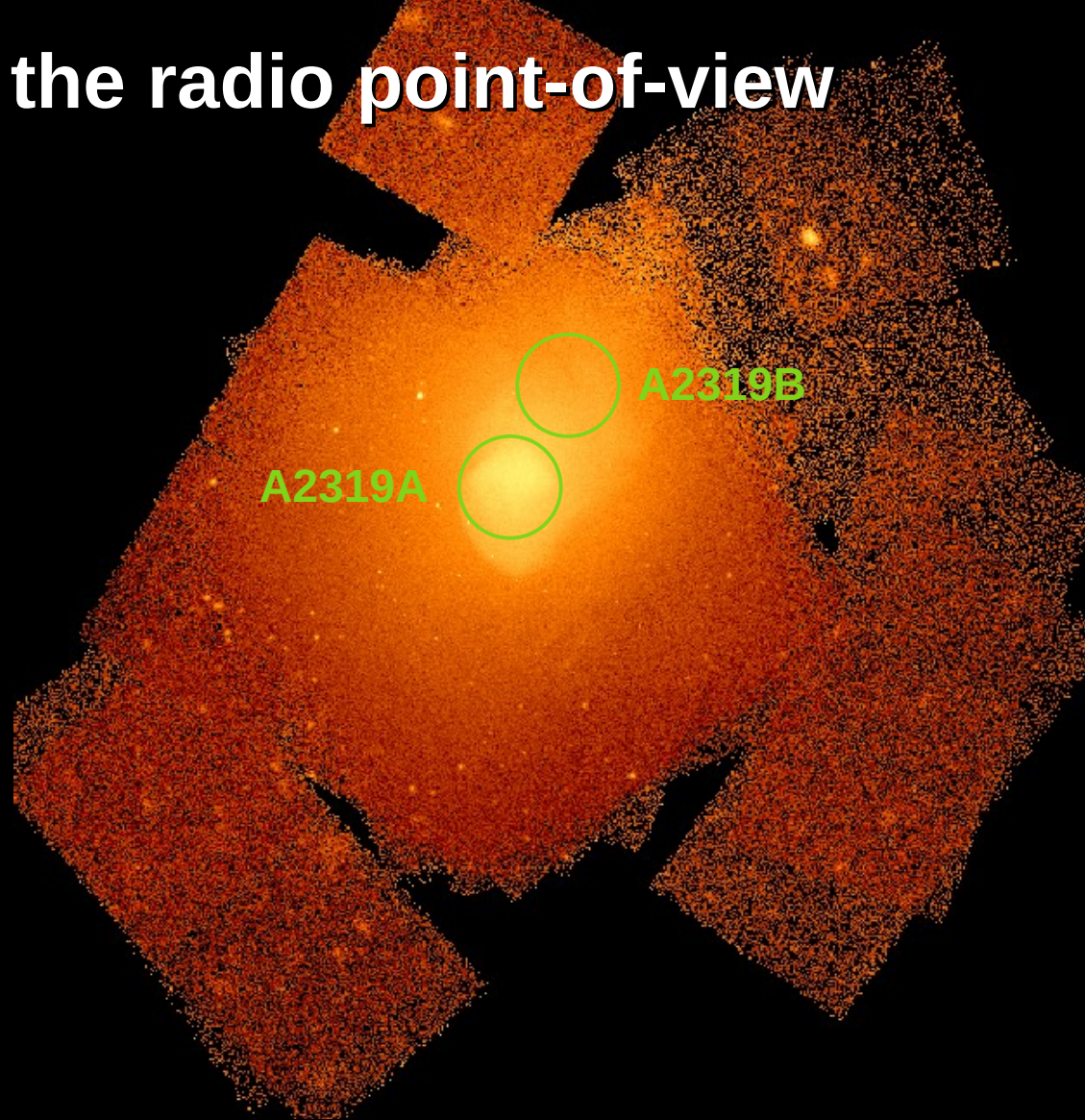
- high-contrast cold front

Abell 2319: a nearby and well-studied galaxy cluster



- **velocity dispersion** higher in the area of the main cold front
→ does **sloshing** induce **turbulence**?

Abell 2319: the radio point-of-view



Abell 2319: the radio point-of-view

observation:

- cluster-wide diffuse radio synchrotron emission
- presence of magnetic fields throughout the ICM
- relativistic electrons produced in-situ

scenarios:

- Fermi-II re-acceleration (of mildly relativistic electrons) through ICM turbulence
 - turbulence induced due to merger activity
- cosmic-ray electrons produced via **hadronic collisions**

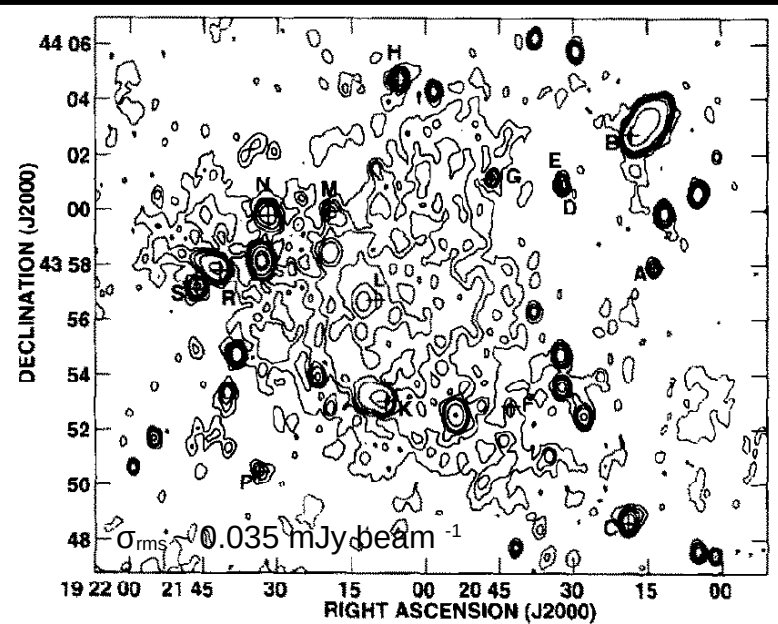
constraints:

- correlation with X-ray surface brightness
- spatial / integrated spectrum



Abell 2319: the radio point-of-view

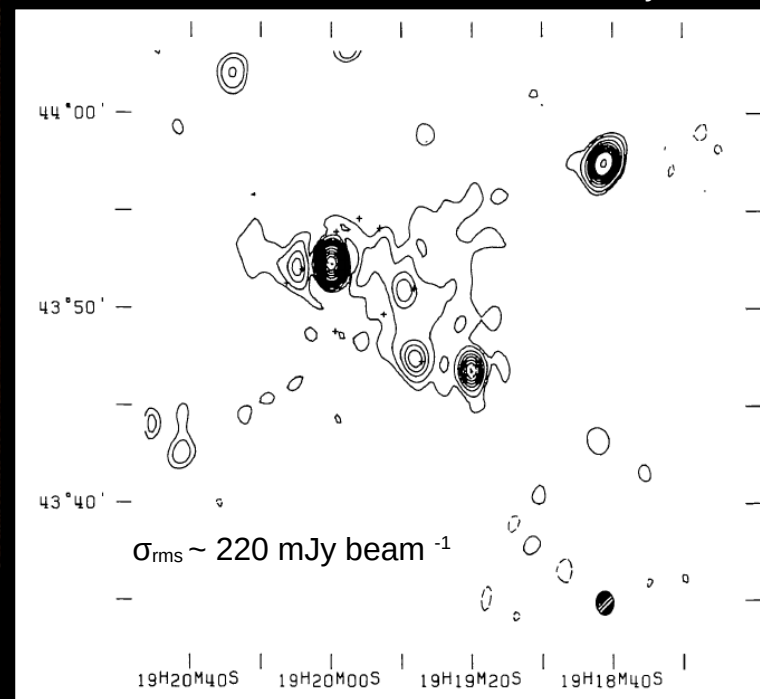
VLA 1.4 GHz -- Feretti+1997



A2319A

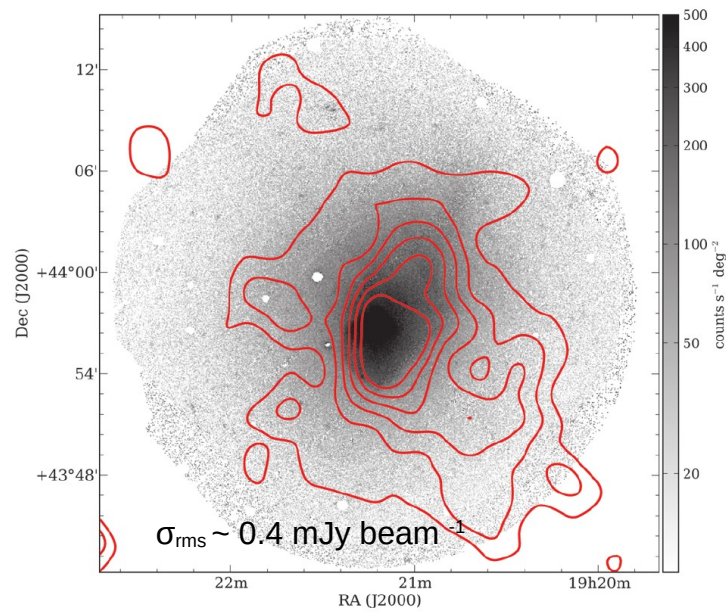
A2319B

WSRT 610 MHz -- Harris & Miley 1978



Abell 2319: the radio point-of-view

VLA 1.4 GHz / XMM Newton -- Storm+2015

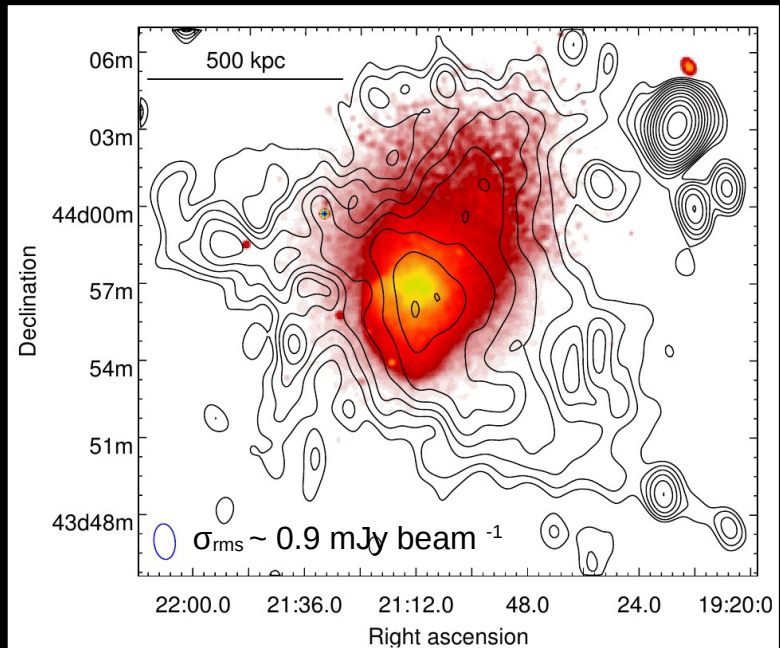


A2319A

A2319B

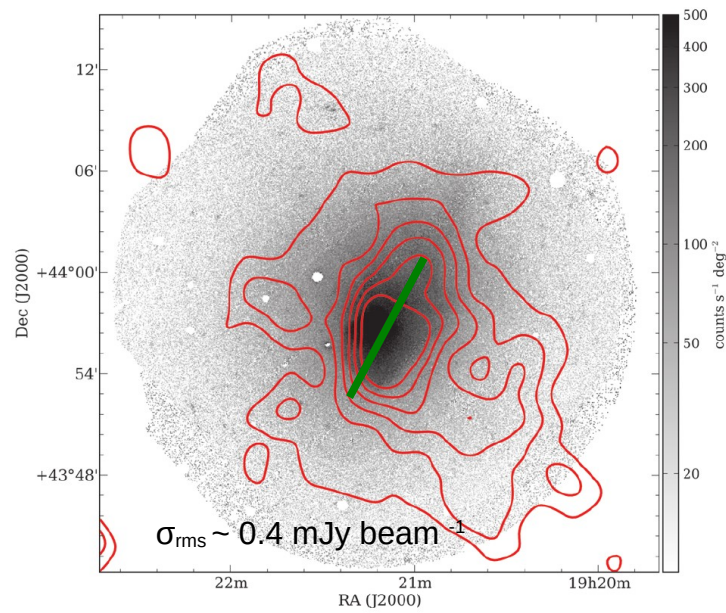
WSRT 346 MHz

X-ray (Chandra 0.5 – 7.0 keV)



Abell 2319: discussed scenario so far

VLA 1.4 GHz / XMM Newton -- Storm+2015



Storm+2015:

multiple component radio emission:

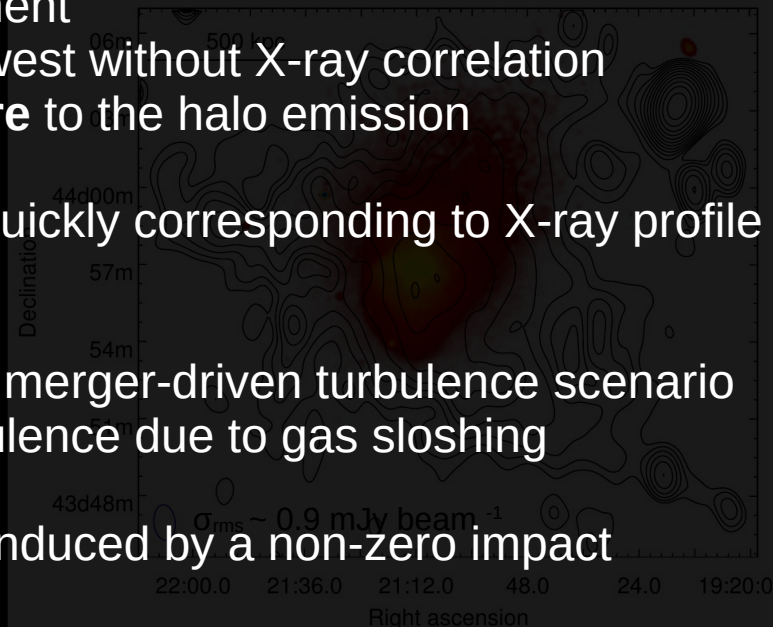
- **2000** kpc main component
- extension to the southwest without X-ray correlation
- embedded **800** kpc core to the halo emission
 - traces X-ray core
 - brightness drops off quickly corresponding to X-ray profile

main-component: usual merger-driven turbulence scenario

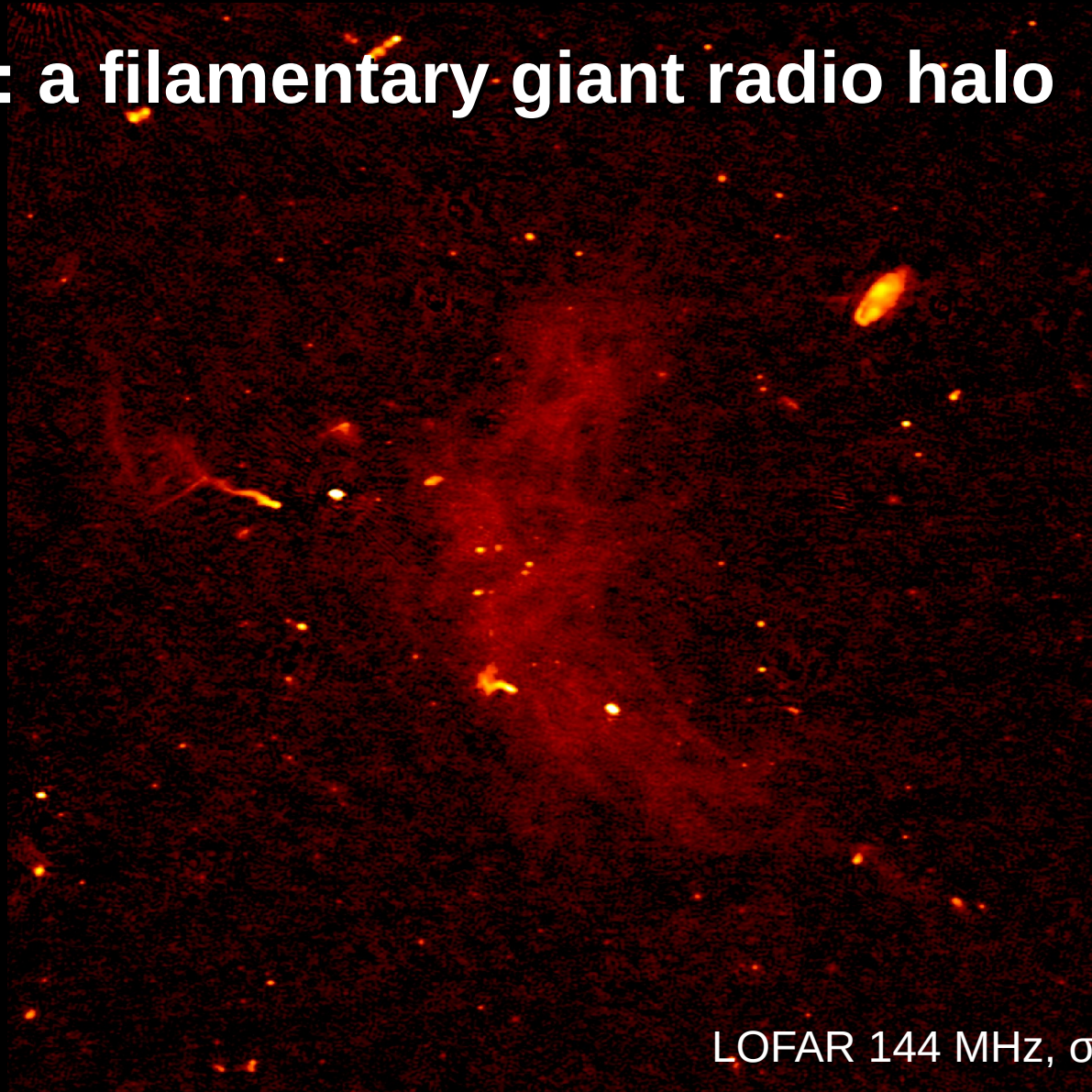
core-component: turbulence due to gas sloshing

- gas sloshing could be induced by a non-zero impact parameter

X-ray (Chandra 0.5 – 7.0 keV)

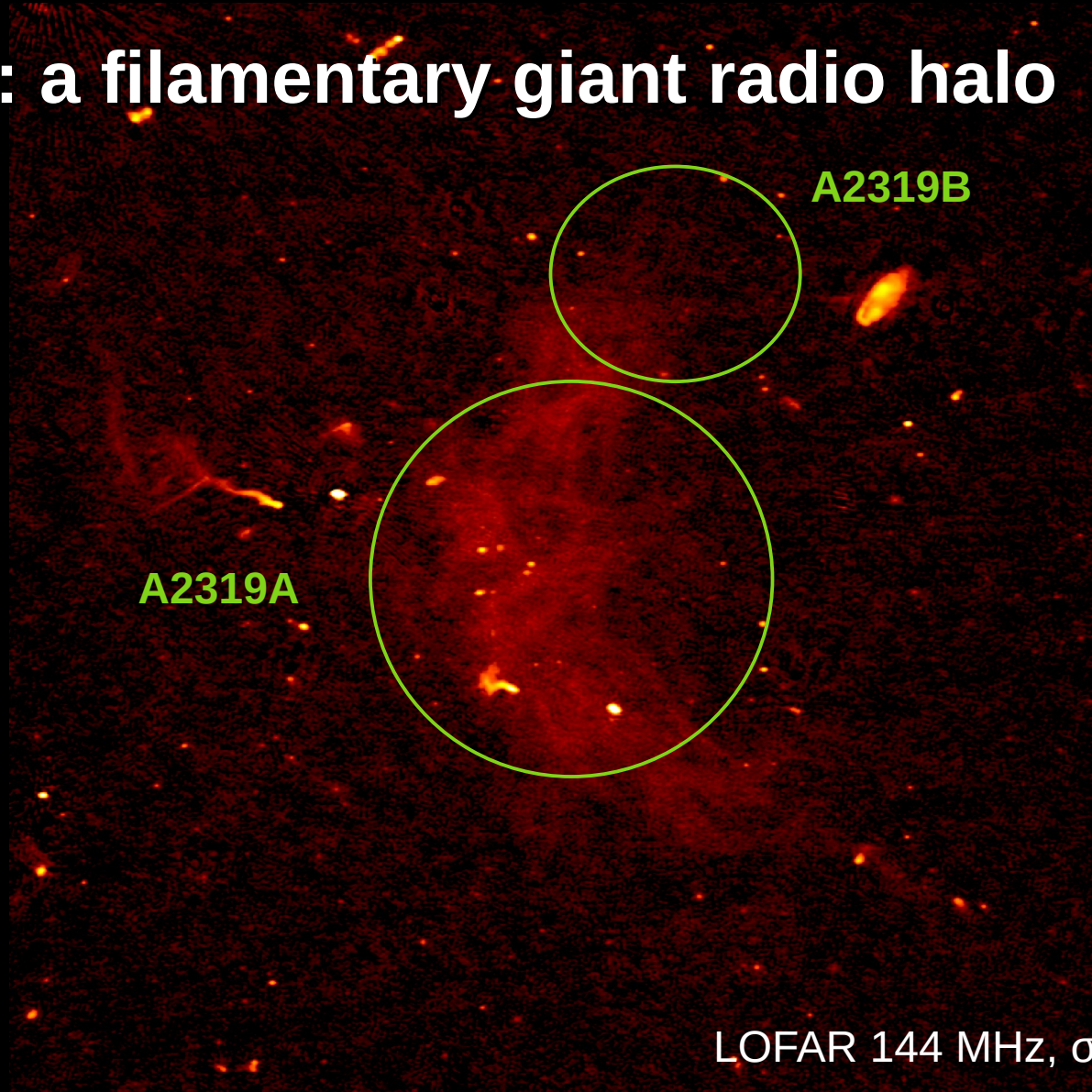


Abell 2319: a filamentary giant radio halo



LOFAR 144 MHz, $\sigma_{\text{rms}} \sim 0.5 \text{ mJy beam}^{-1}$

Abell 2319: a filamentary giant radio halo



LOFAR 144 MHz, $\sigma_{\text{rms}} \sim 0.5 \text{ mJy beam}^{-1}$

Abell 2319: a filamentary giant radio halo

extention towards east not
confirmed, most likely extended
emission from a radio galaxy

filamentary
structure

filamentary structure
In low-density environment
(almost same surface brightness)

LOFAR 144 MHz, $\sigma_{\text{rms}} \sim 0.5 \text{ mJy beam}^{-1}$

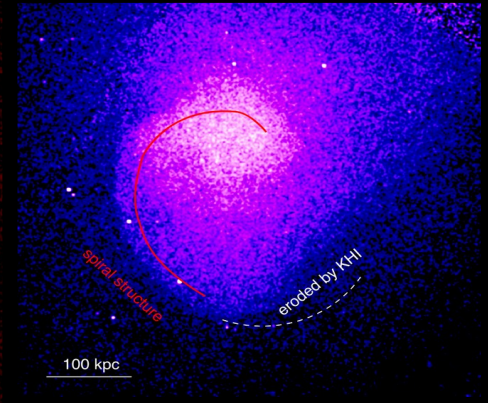
Abell 2319: where is the cold front?

extention towards east not confirmed, most likely extended emission from a radio galaxy

filamentary structure

cold front

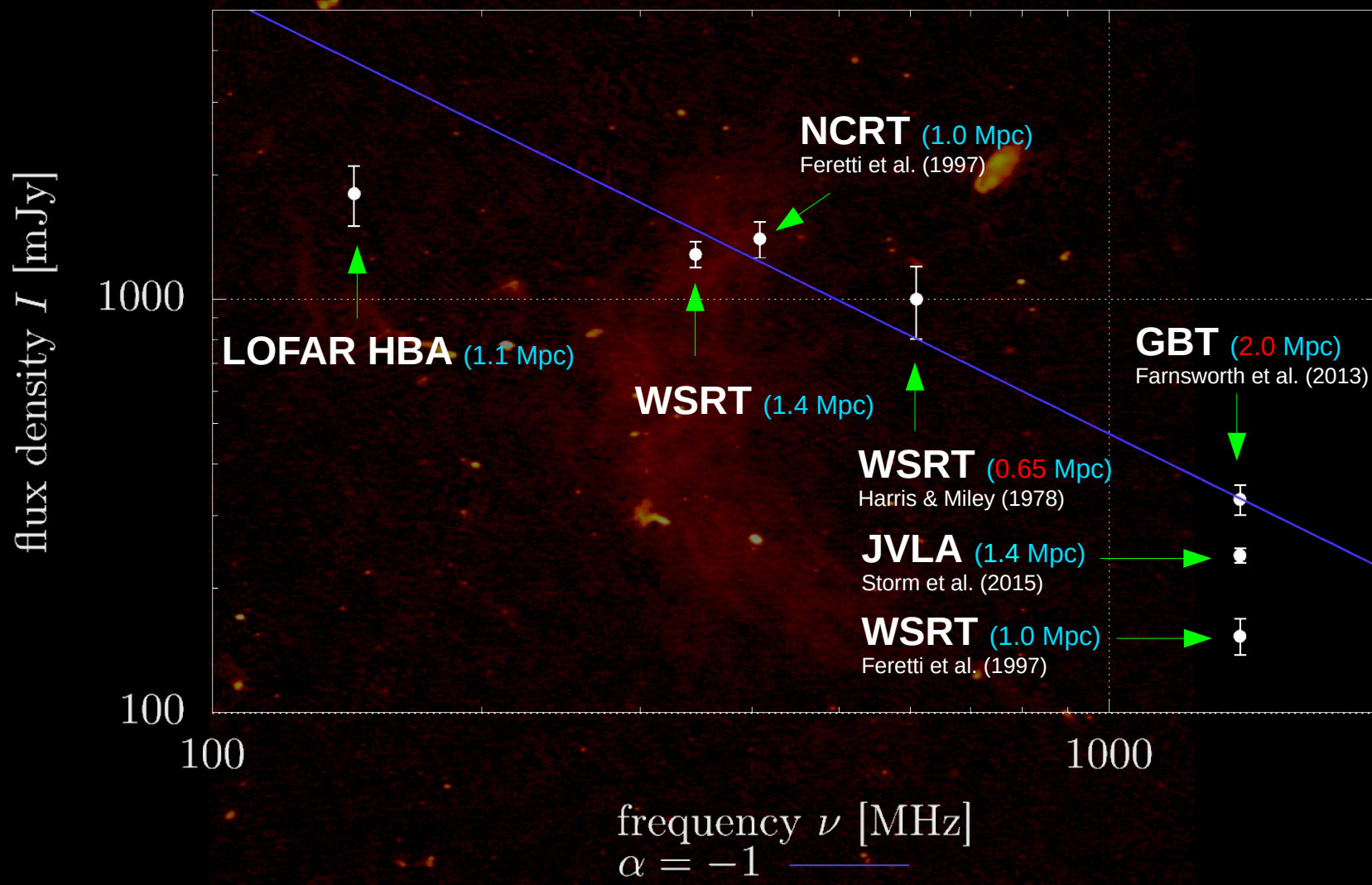
filamentary structure
In low-density environment
(almost same surface brightness)



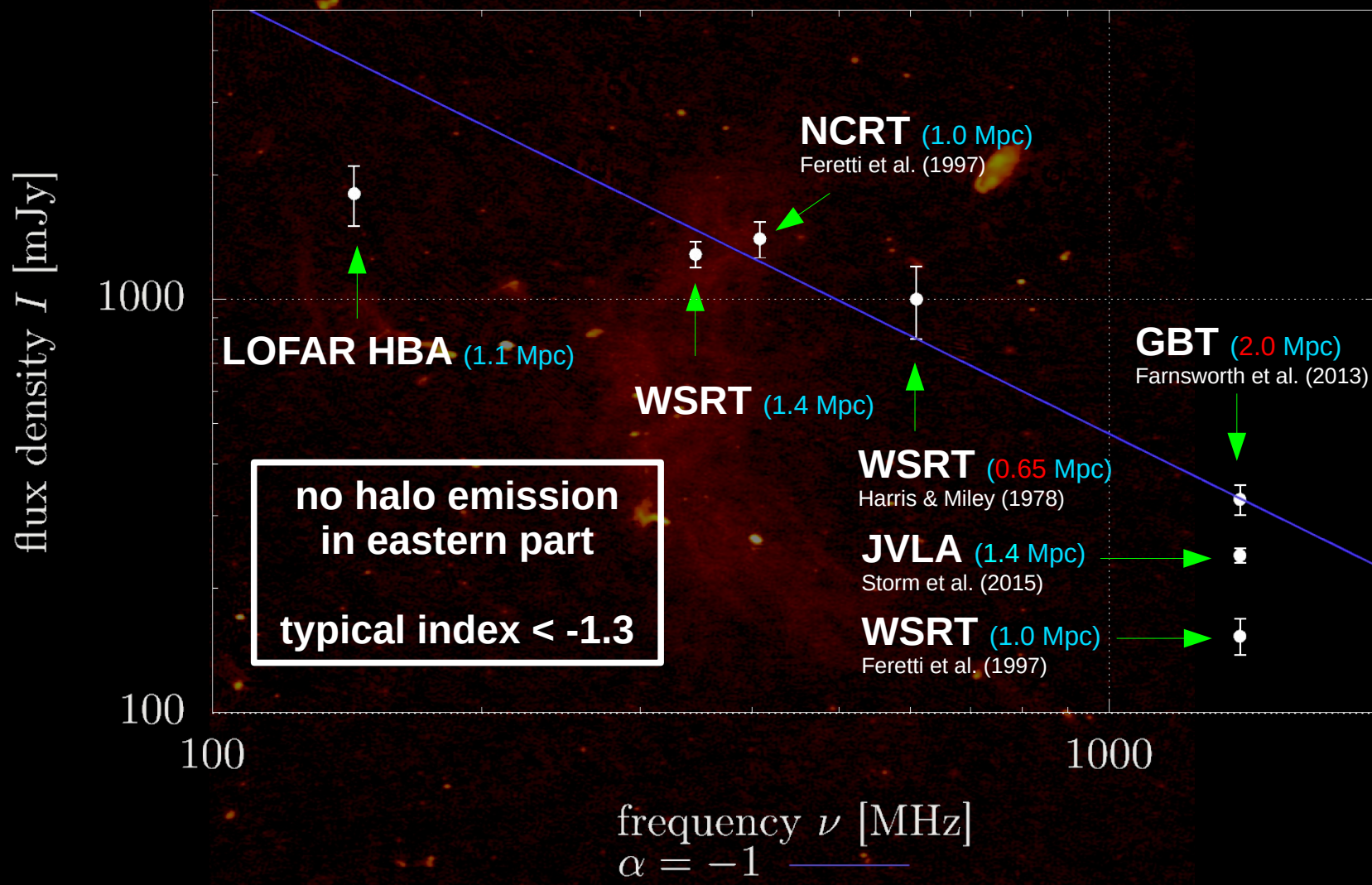
- patchy / filamentary structure
- no flux density jump at cold front
- „banana“ shape“, only partially follows X-ray emission

LOFAR 144 MHz, $\sigma_{\text{rms}} \sim 0.5 \text{ mJy beam}^{-1}$

(integrated) spectral index α of the radio halo in Abell 2319

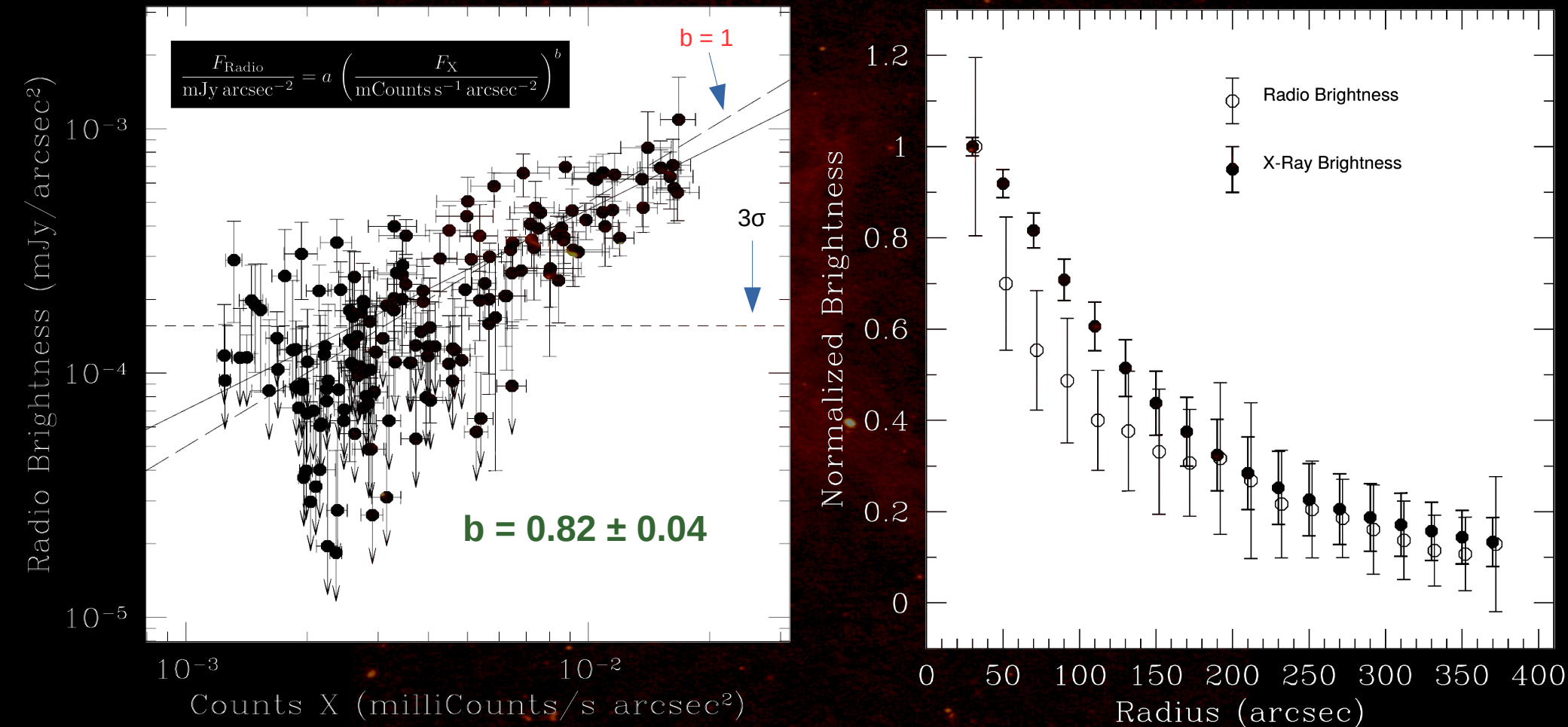


(integrated) spectral index α of the radio halo in Abell 2319



Abell 2319: correlation between X-ray and radio

Govoni+2001 (using VLA data from Feretti+1997)



Abell 2319: implications on the emission origin

- strong correlation between radio and X-ray emission
- thermal and non-thermal components are “mixed”

$$F_{\text{Radio}} \propto F_{\text{X}}$$

thermal component: **dissipation** of kinetic energy of gas falling into cluster's potential (e.g. shock waves, turbulent cascades, ...)

non-thermal components: amplification of **magnetic fields**, **Fermi II** acceleration

assumption:

energy fraction put into non-thermal component is independent of location in cluster

$$j_{\text{X}} \propto n_{\text{e}}^2 (kT_{\text{e}})^{1/2}$$

**thermal
emission**

X-ray emissivity

electron number
density

electron
temperature

Abell 2319: implications on the emission origin

(Govoni+2021)

hadronic scenario

$$\longrightarrow j_{\text{Radio}}/j_X \propto kT^{1/2} \epsilon_B / (\epsilon_B + \epsilon_{\text{cmb}})$$

(Dolag & Enßlin 2000)

- **weak** fields :
→ proportional to **magnetic field density**
- **strong** fields :
→ independent of **magnetic field density**

In case of a radially decreasing magnetic field
strong fields → **linear** relation
weak fields → **super-linear** relation

assumptions:

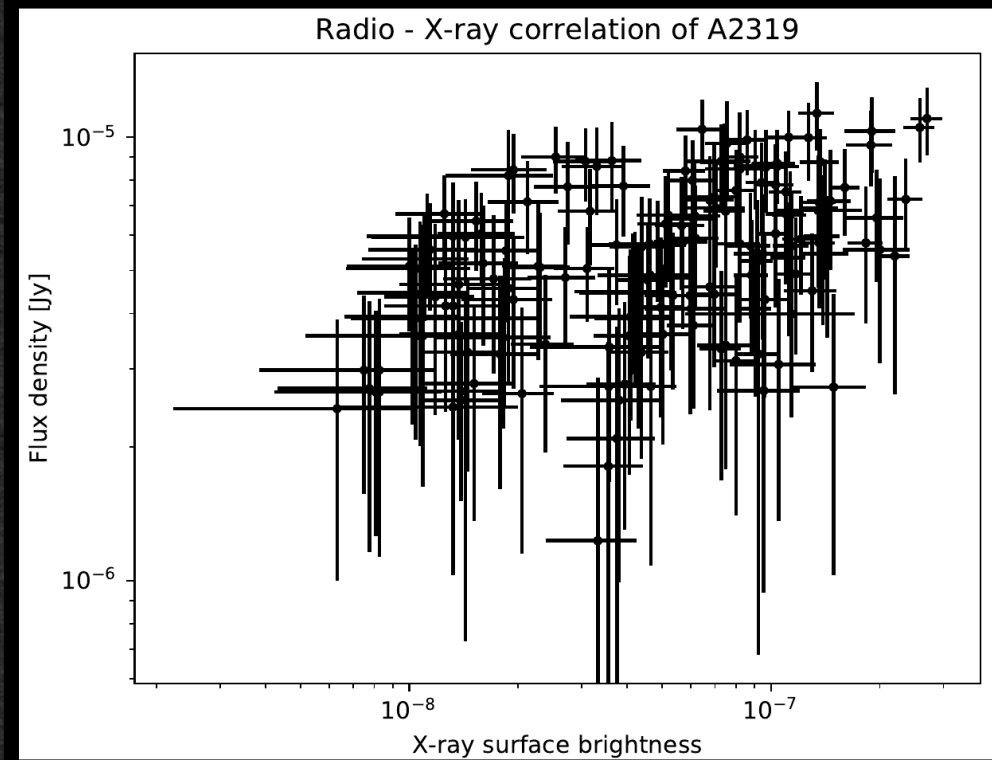
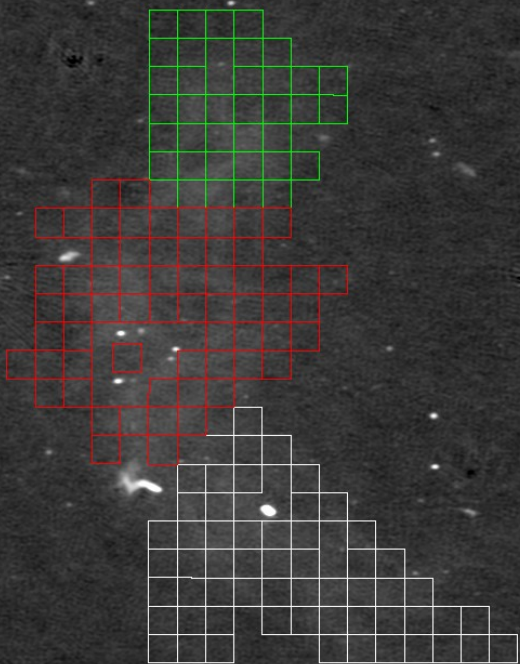
- energy fraction put into non-thermal component is independent of location in cluster
- isothermal cluster, isospatial spectral index distribution
- $\epsilon_B \propto \epsilon_{\text{th}}$ $\epsilon_{\text{CRe}} \propto \epsilon_{\text{th}}$

Abell 2319: what are typical X-ray – radio slopes?

cluster	slope	classification	reference
A2255	1.08 ± 0.06	giant halo	Botteon+2020
A2744	0.67 ± 0.02	giant halo	Rajpurohit+2021
Coma	0.64 ± 0.07	giant halo	Govoni+2011
A2319	0.82 ± 0.04	giant halo	Govoni+2011
Ophiuchus	1.6 ± 0.1	mini-halo	Govoni+2009
A2163	0.64 ± 0.05	giant halo	Feretti+2001
A1689	0.42 ± 0.02	(small) halo	Vacca+2011
A3562	0.67 ± 0.12	giant halo	Giacintucci+2005
MACS J0717.5+3745	0.67 ± 0.02	giant halo	Rajpurohit+2021
MS 1455.0+2232	1.15 ± 0.06	mini-halo	Riseley+2022
RX J1720.1+2638	1.78 ± 0.22	mini-halo	Biava+2021
A3444	1.29 ± 0.14	mini-halo	Ignesti+2020

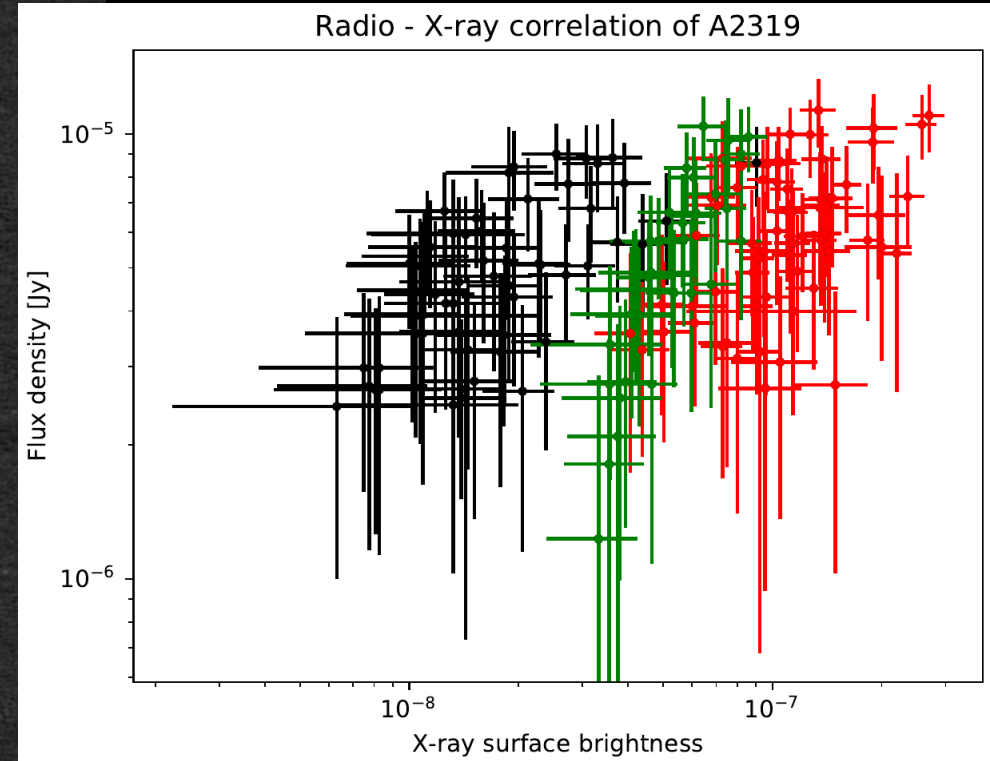
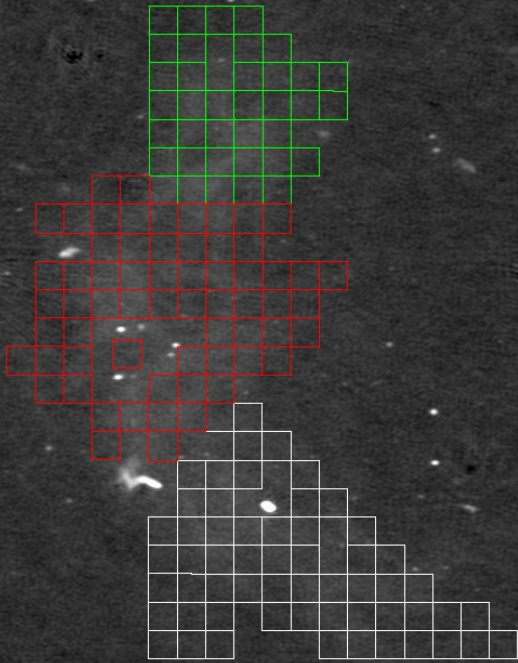
flatter correlation could mean that extra energy component is present, e.g. via turbulence

Abell 2319: Radio – X-ray correlation at 144 MHz



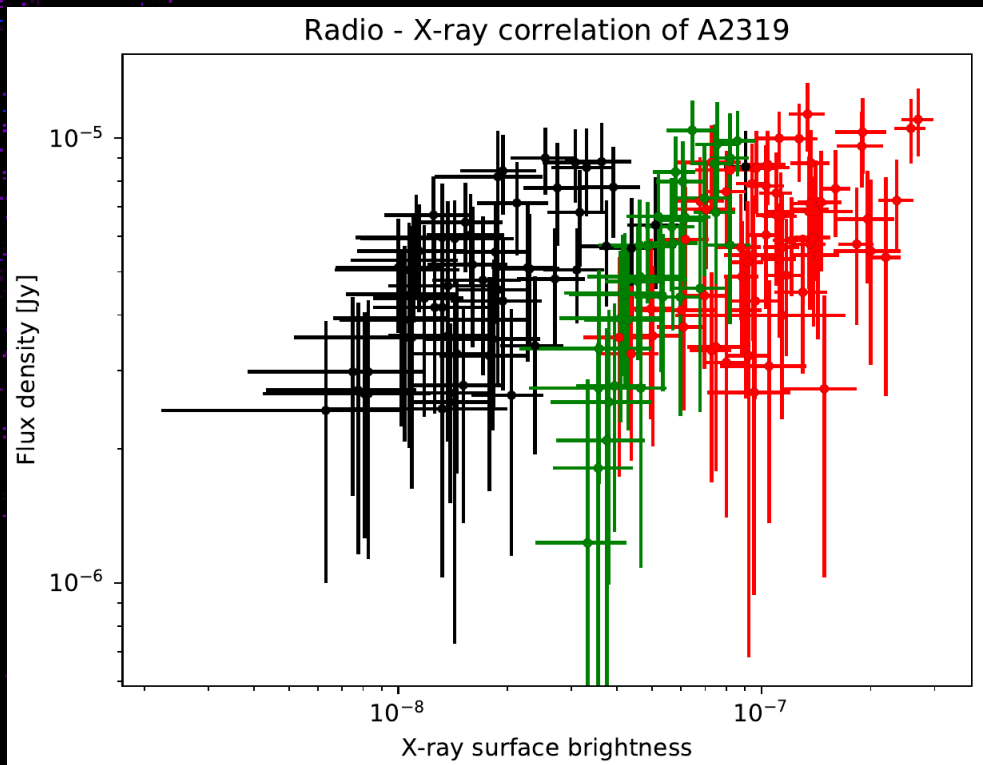
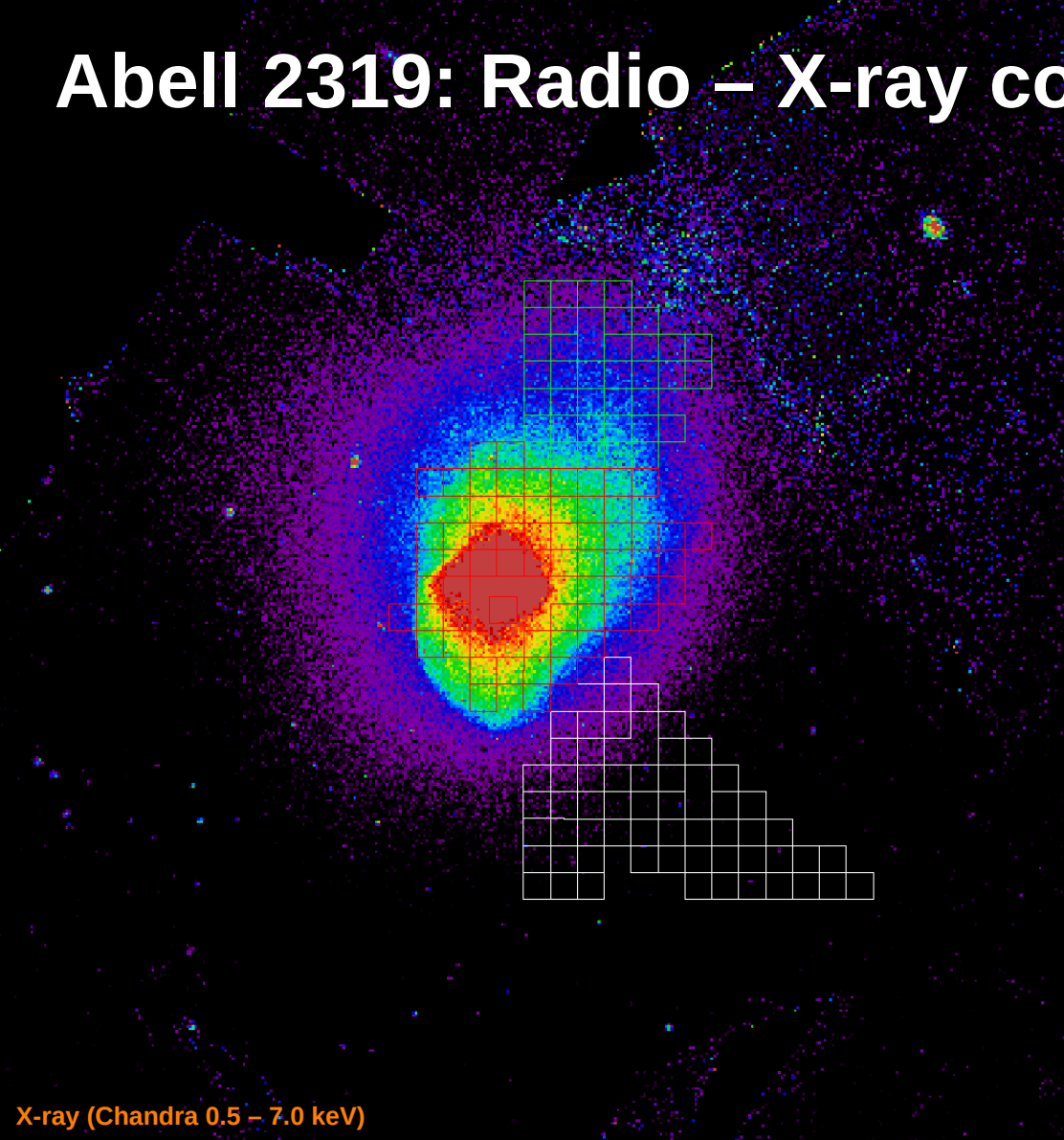
LOFAR 144 MHz, $\sigma_{\text{rms}} \sim 0.5 \text{ mJy beam}^{-1}$

Abell 2319: Radio – X-ray correlation at 144 MHz



LOFAR 144 MHz, $\sigma_{\text{rms}} \sim 0.5 \text{ mJy beam}^{-1}$

Abell 2319: Radio – X-ray correlation at 144 MHz



overall $\sim 0.21 \pm 0.03$

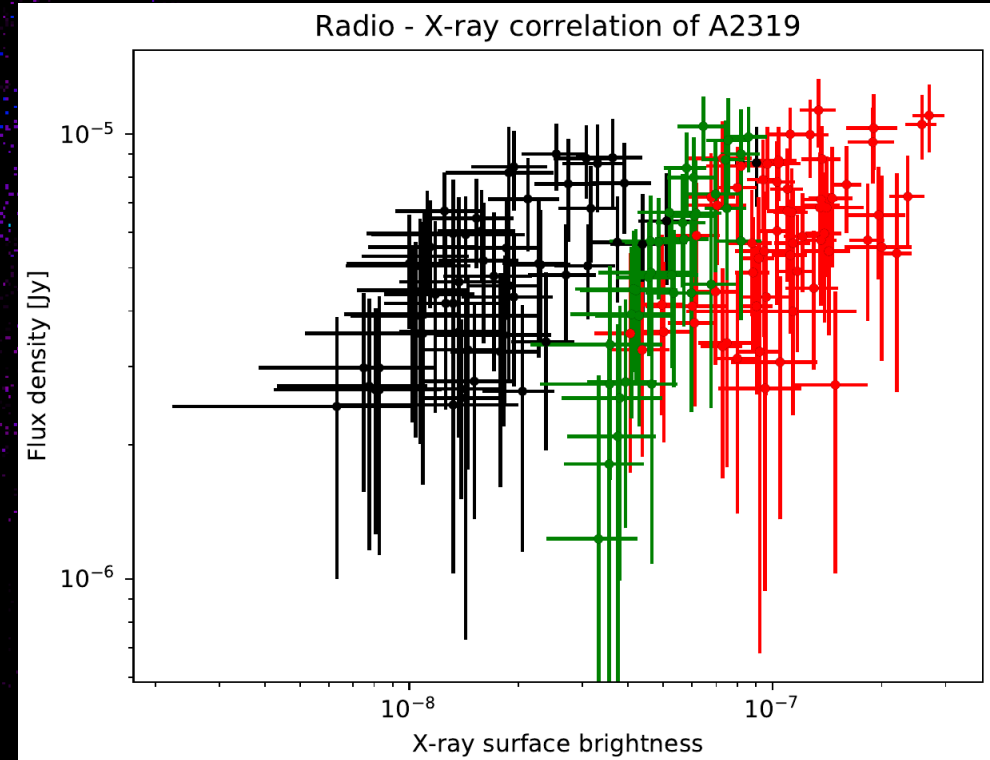
$g = 1.2 \pm 0.2$

$r = 0.4 \pm 0.1$

X-ray (Chandra 0.5 – 7.0 keV)

Abell 2319: Radio – X-ray correlation at 144 MHz

- no clear correlation overall
- linear and sub-linear slope (outskirts / core)
- connected to velocity dispersion?
- confirmation of two different emission mechanisms, no „double-halo“ confirmed
 - need to repeat with varying cell sizes
 - determine statistical significance

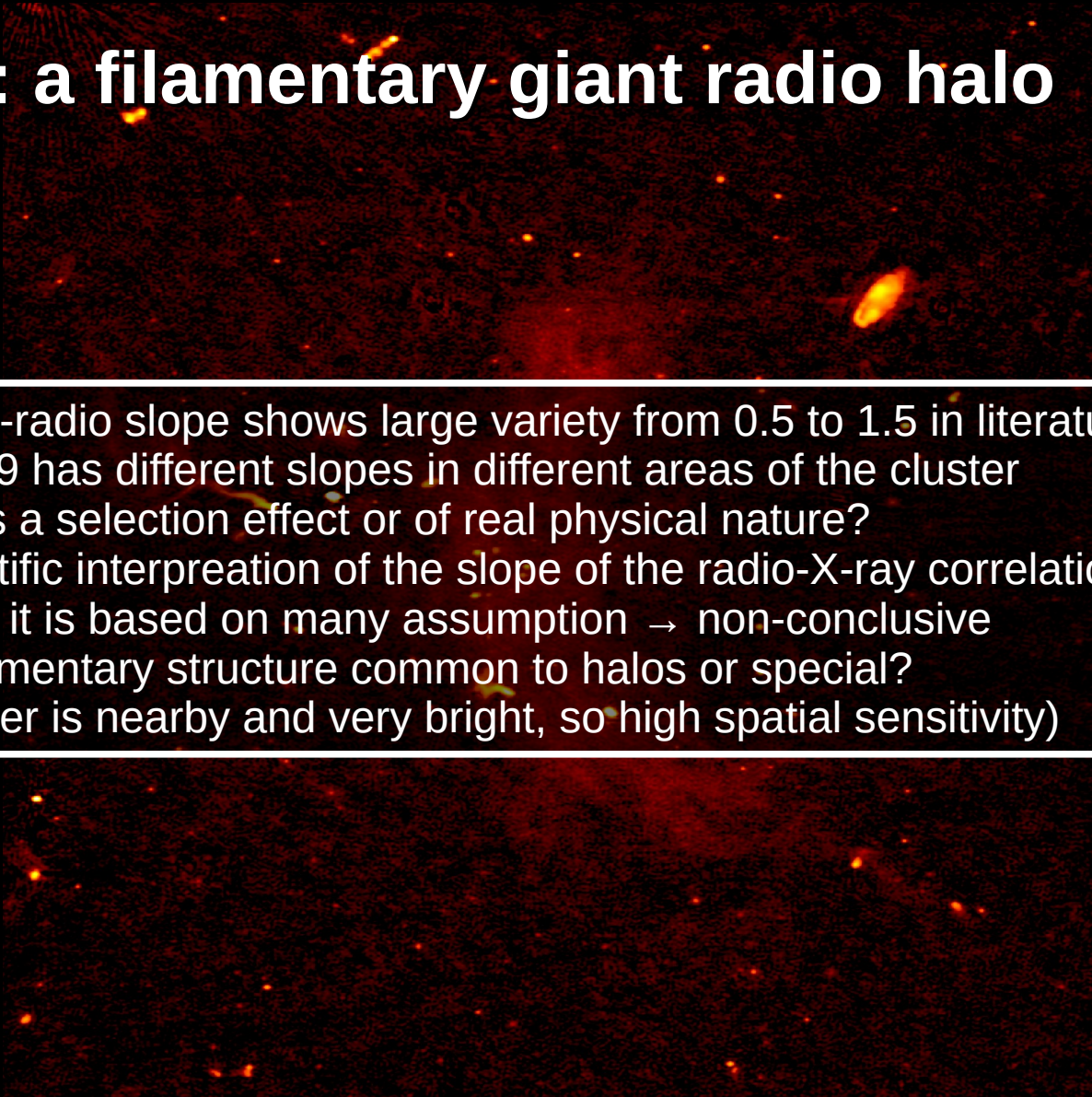


overall $\sim 0.21 \pm 0.03$

$g = 1.2 \pm 0.2$

$r = 0.4 \pm 0.1$

Abell 2319: a filamentary giant radio halo

The background of the slide is a deep red astronomical image of the Abell 2319 galaxy cluster. It shows a dense field of galaxies, with a prominent, bright, elongated filamentary structure visible in the upper right quadrant. The overall texture is grainy, typical of radio or X-ray astronomical observations.

- X-ray-radio slope shows large variety from 0.5 to 1.5 in literature
- A2319 has different slopes in different areas of the cluster
is this a selection effect or of real physical nature?
- scientific interpretation of the slope of the radio-X-ray correlation is limited,
since it is based on many assumption → non-conclusive
- is filamentary structure common to halos or special?
(cluster is nearby and very bright, so high spatial sensitivity)



Questions?