A Multiwavelength View of the HST Frontier Cluster MACS J0416.1-2403

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0.5 - 3 keV Chandra surface brightness map, based on 180 ks of data (Ps: Murray, Jones).
$z = 0.40$
$T = 9.6 - 10.3\ \text{keV}$

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T = 9.6 - 10.3 keV
Total mass within a radius of 950 kpc:
\(~1\times10^{15} \text{ M}_\odot\)

\(\approx 200 \text{ kpc}\)

- **S1**
  - \(M \sim 4\times10^{13} \text{ M}_\odot\)

- **S2**
  - \(M \sim 1\times10^{13} \text{ M}_\odot\)

- **C1**
- **C2**

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Jauzac et al. (2014)
**SCENARIO 1**

A pre-merger system:

C2 approaches C1 for the first time.

**SCENARIO 2**

A post-merger system:

C2 approaches C1 for the second time.

Jauzac et al. (2014)
Is C1 a cool core?
0.5 - 3 keV Chandra surface brightness map, based on 180 ks of data (PIs: Murray, Jones).
Peaked central brightness BUT...

High ellipticity

600 kpc
Peaked central brightness BUT...

- High ellipticity
- Deviations from symmetry

600 kpc
Peaked central brightness BUT...

- High ellipticity
- Deviations from symmetry
- Hot, high-entropy core

$T \approx 13 \text{ keV}$
$n \approx 5 \times 10^{-3} \text{ cm}^{-3}$

Sanderson et al. (2009)
Peaked central brightness BUT...

- High ellipticity
- Deviations from symmetry
- Hot core

600 kpc
Peaked central brightness BUT...

High ellipticity

Deviations from symmetry

Hot core

Distance [arcmin]

SB [counts s^{-1} arcmin^{-2}]

χ

DOUBLE β-model
Peaked central brightness BUT…

- High ellipticity
- Deviations from symmetry
- Hot core
- Evidence of a 2nd subcluster

\[ \text{SB [counts s}^{-1} \text{arcmin}^2] \]

\[ \chi \]

\[ 5 \times 10^{-2} \quad 10^{-1} \quad 2 \times 10^{-1} \quad 3 \times 10^{-1} \quad 1 \quad 2 \quad 3 \quad 4 \]

\[ \text{Distance [arcmin]} \]
The ratio:

\[ R_S = \frac{S_{0,1}}{S_{0,2}} \]

is closest to 1 in the direction of the “hidden” subcluster.
C1 is undergoing a merger with a less massive cluster not immediately visible in the X-ray map.
Is C2 a relaxed cluster?
\[ \beta = 0.6 \text{ (fixed)} \]

\[ r_c = 150 \pm 5 \text{ kpc} \]
$\beta = 0.6$ (fixed)

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$r_c = 150 \pm 5$ kpc
$\beta = 1.6 \pm 0.3$ (free)

$r_c = 460 \pm 70$ kpc
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$r_c = 460 \pm 70$ kpc
C2 is also undergoing a merger with a smaller cluster not immediately visible in the X-ray map.
Provisional Summary

C1 is merging
- strongly elongated
- hot core
- high central entropy
- ICM substructure
- C1 = multiple subclusters

C2 is merging
- flat X-ray brightness
- poor/unphysical $\beta$-model fit
- density discontinuity in the ICM
Are C1 and C2 interacting with each other?
- no clear evidence of typical merger shocks
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C1 and C2 have not yet merged with each other.
Summary

• The HST Frontier cluster MACS J0416.1-2403 is a hot (T \sim 10 \text{ keV}), massive (M \sim 1e15 M_{\odot}) merging cluster.

• The main subclusters are interacting with less massive galaxy groups, as evidenced by substructure and weak density discontinuities in the ICM.

• However, no clear evidence of interaction between the two main subclusters.

• **Likely scenario:** MACS J0416.1-2403 is a place of active cosmic structure growth. We are witnessing a pre-merging system.