First evidence of interaction between relativistic electrons and compressed magnetic field of a merging galaxy cluster

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Abell 3376 is a well known merging cluster and has been subject of many observational studies in optical, radio and x-ray wavelengths. We combined recent high-resolution (5”) MeerKAT 1.283 GHz observations with XMM-Newton x-ray observational results along with numerical simulations to unambiguously unveil, for the first, an evidence of an interaction between compresses magnetic fields produced by the streaming plasma from the center of the merger and the relativistic electrons of a radio galaxy.

MeerKAT observations and reduction

- MeerKAT L-band (856 ~ 1712 MHz) observations was carried out on the 1st June, 2019 (PI: James Chibueze)
- 60 of 64 antennas of the MeerKAT array participated in the observations
- Bandwidth: 856 MHz
- Number of channels: 4096 (~209 kHz per channel)
- Primary flux and bandpass calibrator: J0408-6545
- Gain calibrator: J0538-4405
- OXKAT (https://ascl.net/code/v/2627) used of calibration and imaging

XMM-Newton observations

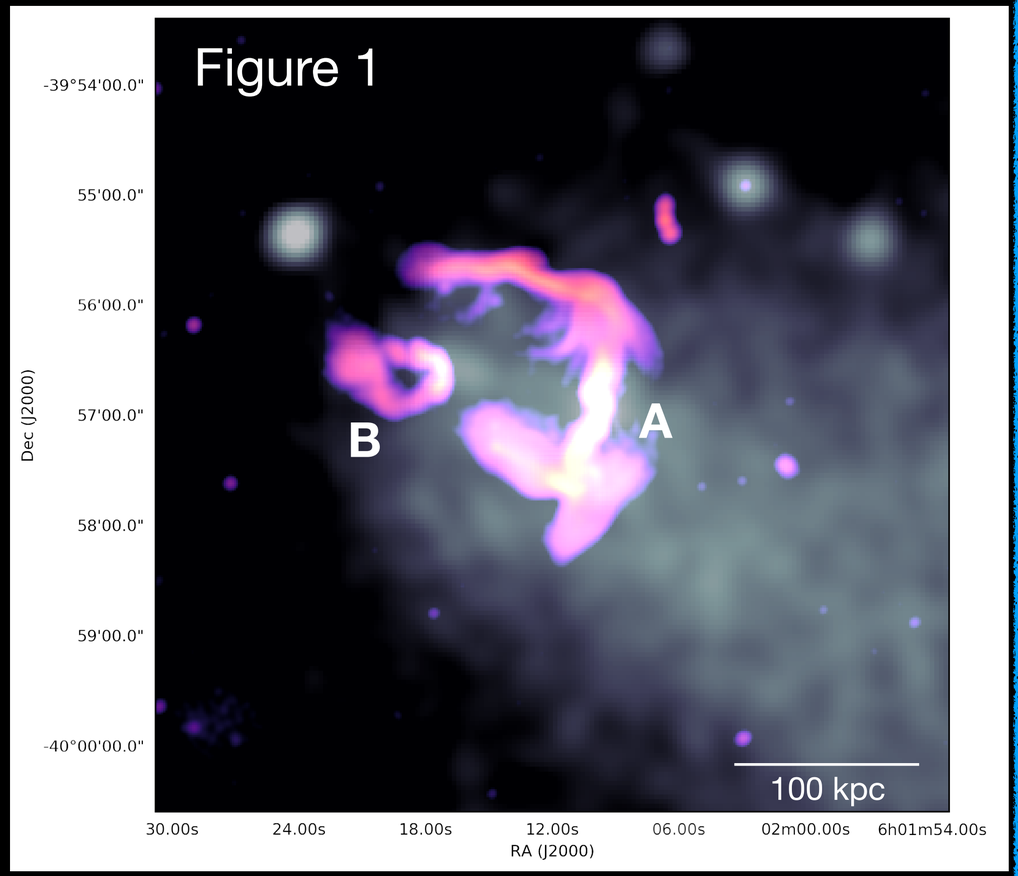
- Observed with EPIC instruments on XMM-Newton X-ray Observatory (OBSID:0151900101)
- 0.5-2.0 keV images produced after proper processing

MeerKAT array

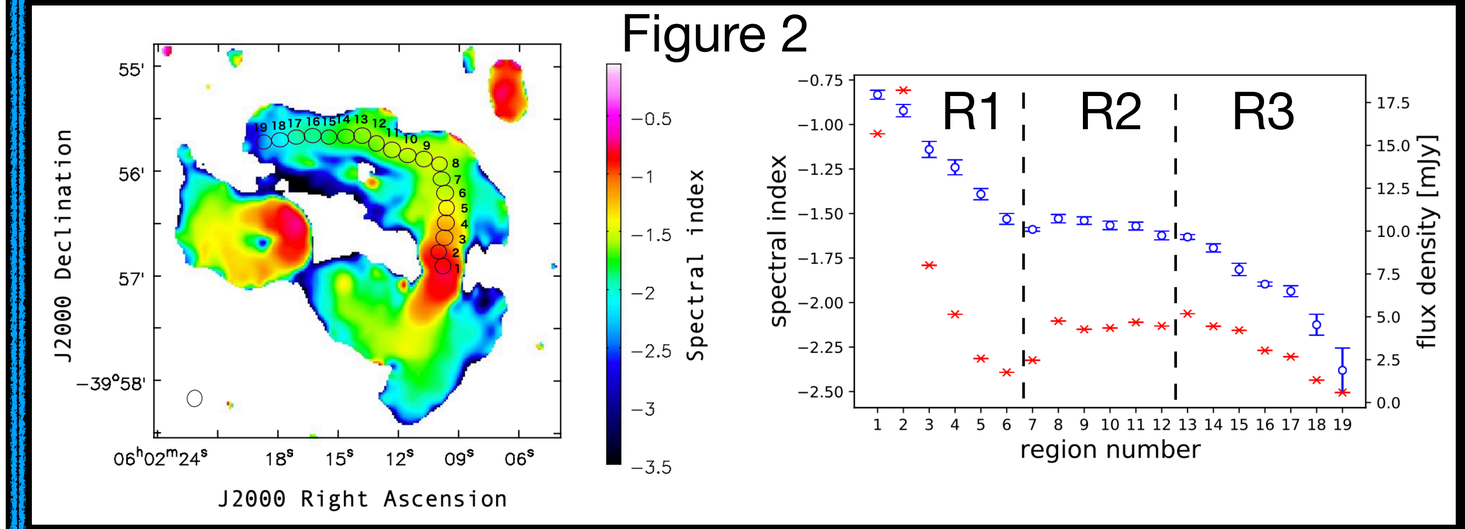
XMM-Newton X-ray telescope

The MeerKAT telescope is operated by the South African Radio Astronomy Observatory, whichis a facility of the National Research Foundation, an agency of the Department of Science and Innovation (DSI).

Main results - Bent radio jet lobes and discontinuous spectral index



MeerKAT 1283 MHz image (Figure1 pseudo color) of radio galaxy in Abell 3376 cluster overlaid on the XMM-Newton x-ray image (gray scale background). A and B radio galaxies can been observed to have bent lobes feature.



Focusing on radio galaxy A, we constructed the spectral index map (Figure 2 left panel) using sub-band images created from the MeerKAT observation. Extracting the flux densities and corresponding spectral indices in the encircled points, we explored the trend in the changes in intensities of the radio emission and spectral indices.

Three distinct trends (R1, R2 and R3) can be observed in Figure 2 (right panel). R1 show a sharp drop in both intensities and spectral indices, R2 stayed fairly flat in both, while R3 show a slow decay in both intensities and spectral indices.

To understand the reason for the observed trend, our x-ray observation and numerical simulation hold key pieces of the puzzle.

Cold front observed in X-ray

Figure 3

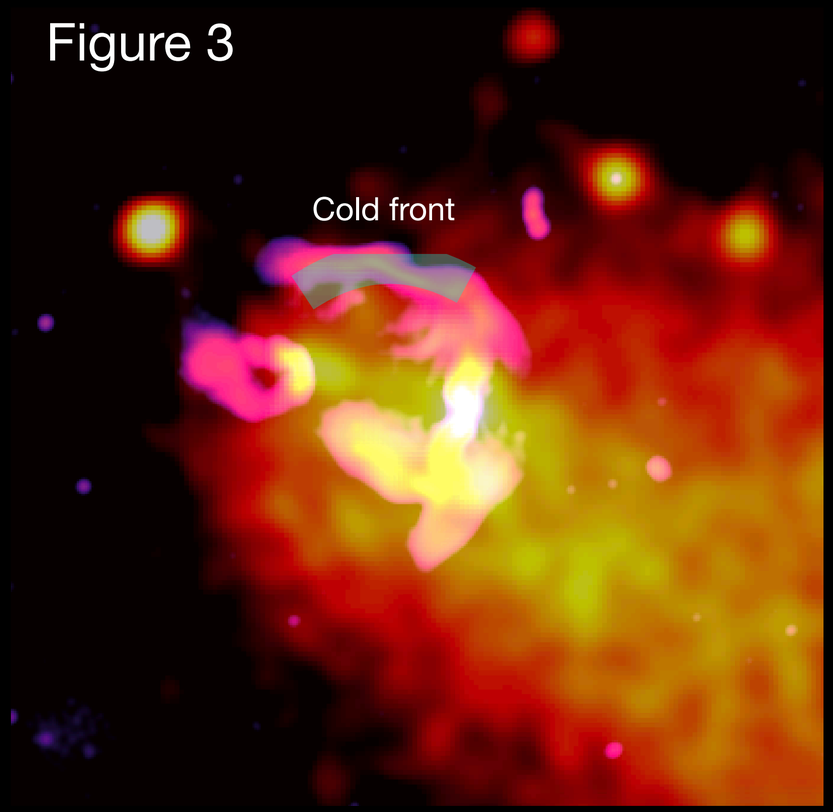
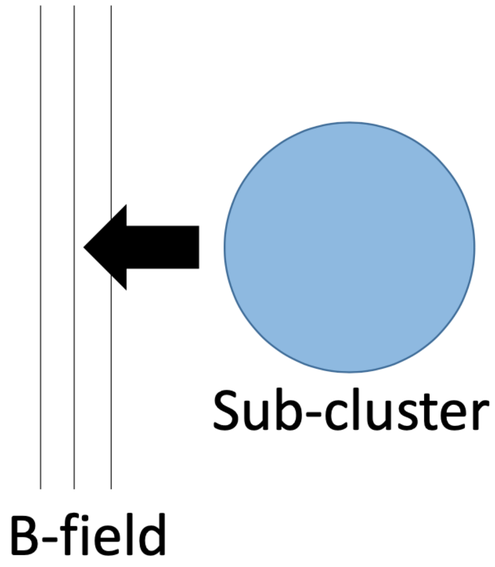


Figure 4



Density + B-field (MHD)

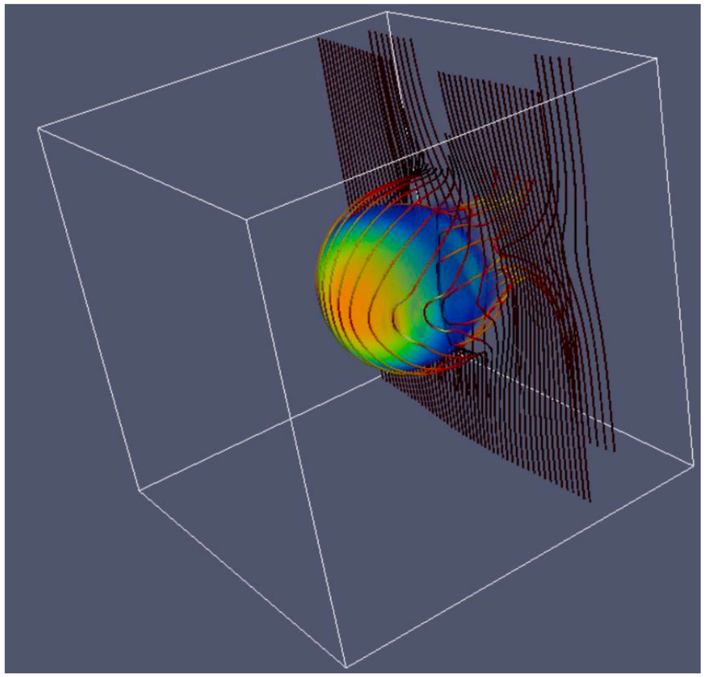


Figure 3 show an image similar to Figure 1 but with an indication of a cold front (with clear temperature discontinuity) observed in x-ray. This is an indication of increased magnetic field created by the compression of the magnetic field around the merging cluster. Forming of such cold front and magnetic field layer have been shown to be possible by Asai et al. 2004, 2007 (see also Figure 4).

Numerical simulation results and conclusions

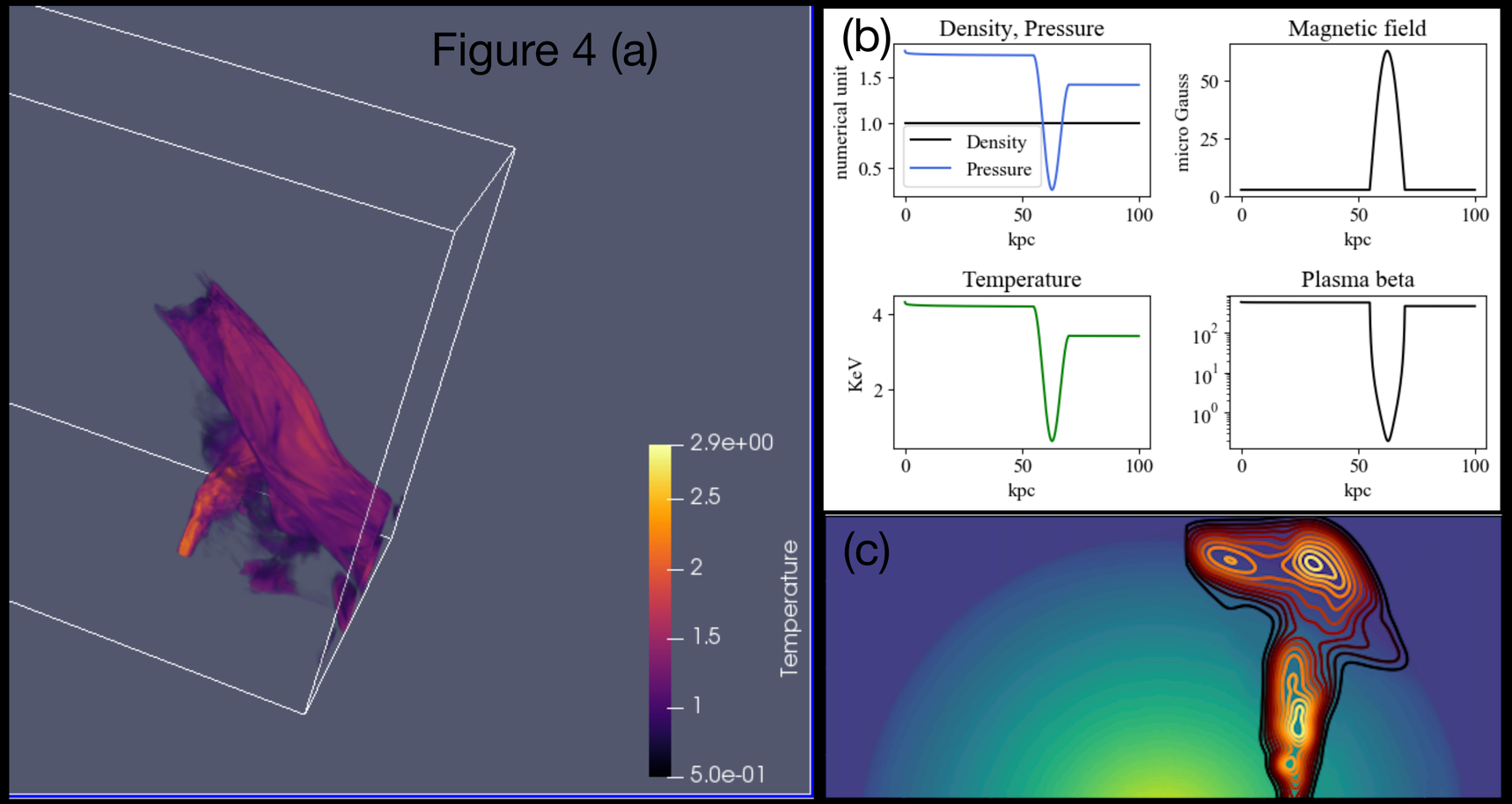


Figure 4 shows our numerical simulation results (a. 3-D view of the bent jet lobe due to relativistic electron interaction with the compressed magnetic field of the merging cluster, Abell 3376, (b) initial conditions of the simulations) and (c) 2-D view of the same results). These results confirm the observed R1, R2, R3 trends in intensities, especially the brightening observed in R2, the point of interaction between relativistic electron and compressed magnetic field.

Conclusions

- We reported the first ever convincing observational evidence of an interaction between relativistic electron and compressed magnetic field of a merging cluster (Abell 3376)
- Numerical simulations supported the observed features and showed a magnetic field of ~ 65 microGauss is required for such interaction.
- Multi-wavelength view of observed features in radio galaxies is undoubtably the best way to unveil the underlying physics behind them.
- These results will completely change our current view of intracluster interactions.
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