A Shock Near the Virial Radius of the Perseus Cluster

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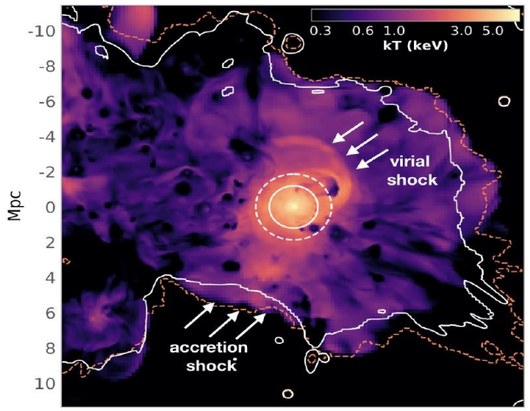
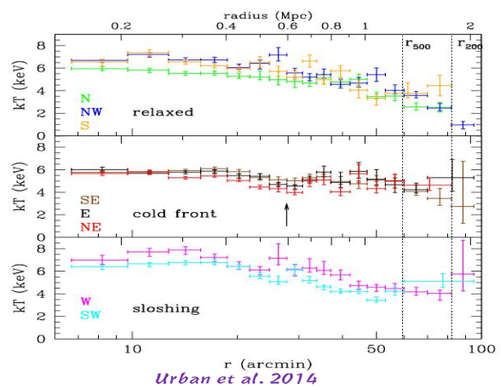
Introduction

The intracluster medium (ICM) is heated to X-ray emitting temperatures by shocks and compression as it falls into the deep gravitational potential wells [1]. Virial shocks and accretion shocks play a key role in heating most of the baryons into a hot and diffuse state. However, neither of these phenomena have been conclusively detected yet [2].



Simionescu et al. 2021



Urban et al. 2014

A previous X-ray study on the Perseus cluster has revealed a sharp temperature jump near r_{200}, with ~25ks Suzaku exposure on average (see the last 2 blue points of northwest (NW) arm in the lower figure) [3]. Deeper exposure can help us more carefully examine this potential shock front near the virial radius.

Abstract

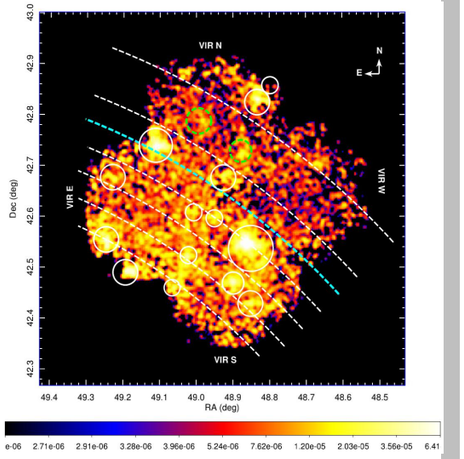
Combining four new Suzaku observations on the northwest outskirts of the Perseus Cluster, we have carefully investigated this interesting region by analyzing the spectra of various annuli and extracting projected thermodynamic profiles. We find that the projected temperature profile shows a break near r_{200}, indicating a shock with M = 1.9 ± 0.3. Corresponding discontinuities are also found in the projected emission measure and the density profiles at the same location. This evidence of a shock front so far away from the cluster center is unprecedented, and may provide a first insight into the properties of large-scale virial shocks which shape the process of galaxy cluster growth.

Suzaku observations

We present the analysis of four new Suzaku pointings covering the outskirts of the Perseus Cluster in the North-West direction, named VIR S, VIR E, VIR N and VIR W. These pointings were taken in 2014 February, each ~25 ks.

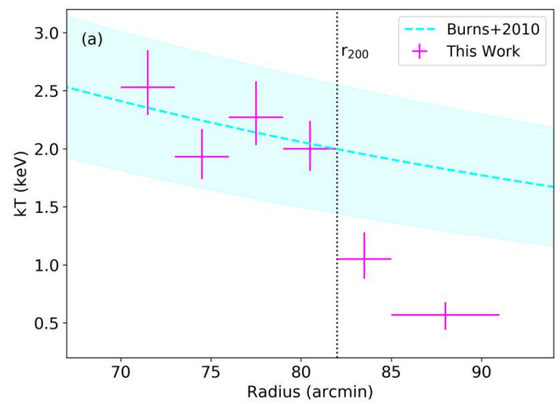
2-4 times deeper exposure

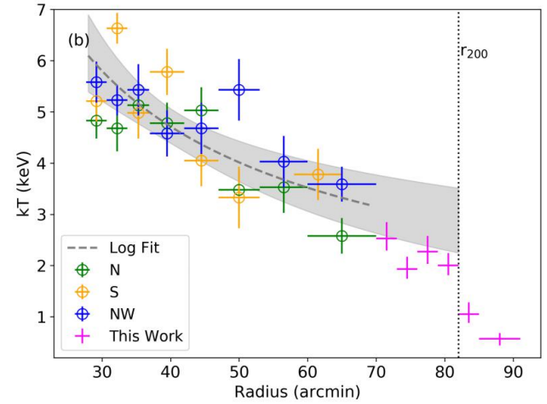
extract spectra from 6 annuli



Thermodynamic properties

A temperature drop from 2.0 ± 0.2 keV to 1.1 ± 0.2 keV, moving outwards, is confirmed near r_{200}. In the same location, a drop in the estimated emission measure (EM = $\int n_e n_H dV$) is detected, resulting in an electron density (n_e) drop from $1.7 \pm 0.1 \times 10^{-4}$ cm^{-3} to $1.1 \pm 0.1 \times 10^{-4}$ cm^{-3}.





The estimated Mach number for this shock candidate is M = 1.9 ± 0.3 with projected temperature ratio, and M = 1.09~1.20 derived from the density compression factor.

Virial shock or merger shock?

Virial shock:

- The location of this shock front near the virial radius.
- It is possible that NW direction probes an azimuth where the virial shock penetrates closer than average to the core, enhancing the probability of detection.
- The simulated Mach number distribution of the "virial shock" [4] covers our measurements.

Merger shock:

- The past merger events occured near the Perseus core could lead to this shock.
- The age of this shock estimated from pre-shock temperature and mach number is ~1.8 Gyr, which is reasonable.

Ref

[1] Ryu, D., Kang, H., Hallman, E., & Jones, T. W. 2003, ApJ, 593, 599

[2] Simionescu, A., Ettori, S., Werner, N., et al. 2021, Experimental Astronomy [arXiv:1908.01778]

[3] Urban, O., Simionescu, A., Werner, N., et al. 2014, MNRAS, 437, 3939

[4] Molnar, S. M., Hearn, N., Haiman, Z., et al. 2009, ApJ, 696, 1640