# Rotation measure analysis of shocks and sloshing fronts in a cluster merger simulation

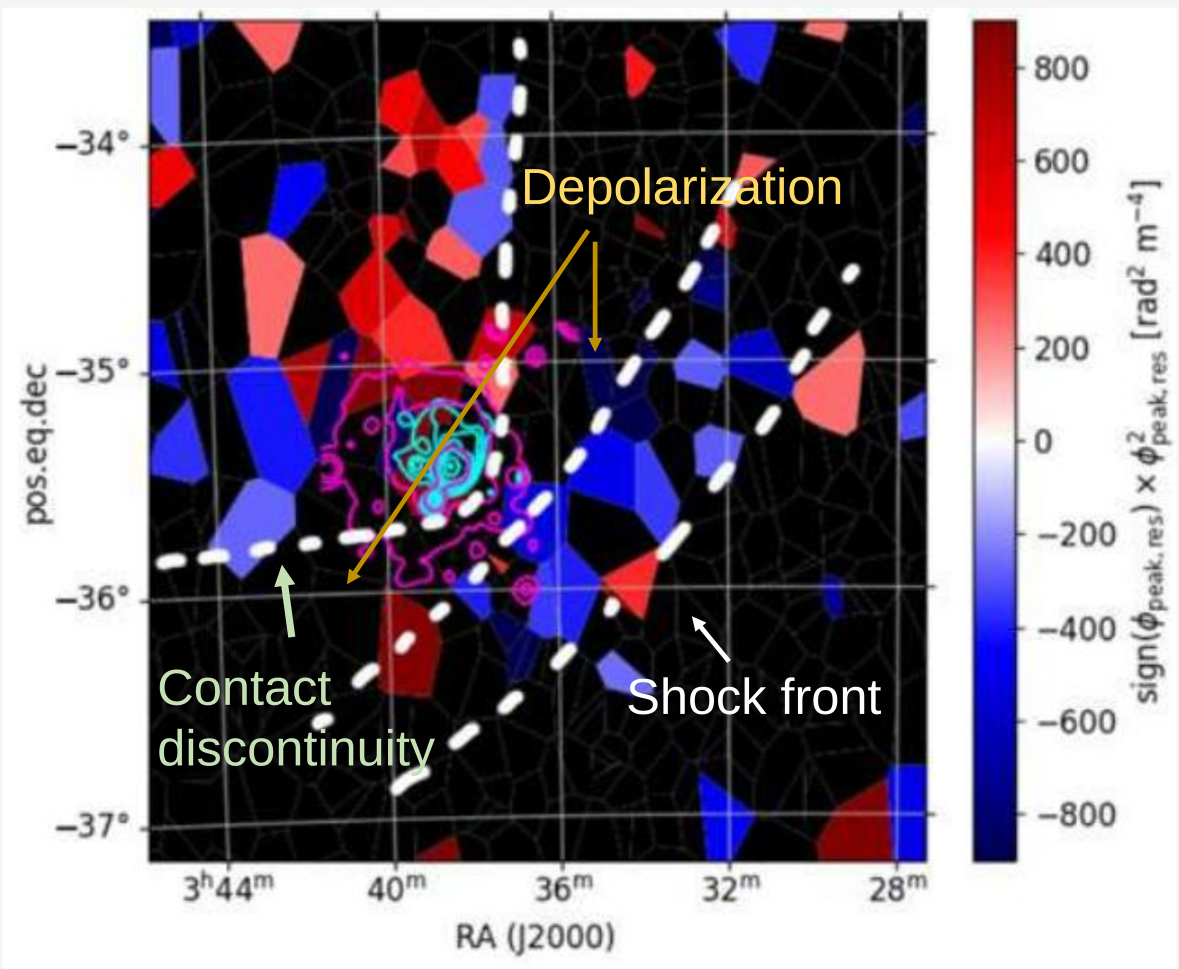
Jia-Rou Liou[1], *H.-Y. Karen Yang*[2], *Alvina Y. L. On*[3]

[1]*Dep. of Physics, National Tsing Hua University, Hsinchu, Taiwan*
[2]*Institute of Astronomy, National Tsing Hua University, Hsinchu, Taiwan*
[3]*Physics Division, National Center for Theoretical Sciences, Taipei, Taiwan*

## Abstract

One of the methods for studying large scale magnetic field structure of the intracluster medium (ICM) is through rotation measure (RM) analysis. By measuring how the linear polarization of background light sources change through the ICM, we may infer the properties of the medium, such as its magnetic field orientations and electron density distributions. Recent RM observations of the Fornax cluster revealed Mpc-scale depolarization features, which may be linked to merger shocks or sloshing motions (Fig 1 below). To investigate this, we analyze the RM maps from a cluster merger scenario in the FLASH simulation. Our results show RM enhancements at the shock fronts, while sloshing motions reduce RM magnitude near the cluster center, likely due to turbulence-induced depolarization. Using polarized radiative transfer (PRT) calculations, we find that uniform background light is more depolarized near the cluster center, with this effect becoming more pronounced as background intensity decreases.

## Motivations




Is the Depolarization region caused by turbulence induced magnetic field entanglement?

Figure 1. Map of Faraday depth (squared to enhance structures) of the Fornax cluster. (Anderson et al. 2021) Cyan contour shows x-ray contour of Fornax ICM taken by Chandra (0.3-1.5 KeV); magenta contour is from ROSAT (0.1-2.4 KeV). There are two Faraday depth enhancement regions, one behind the wake and one between the shock fronts (white dashed lines).

## Introductions

Relations between Rotation Measure (RM) and Faraday depth ($\varphi$)

$$\varphi(s) = \varphi_0 + \frac{2\pi e^3}{{m_e}^2 (c\omega)^2} \int_{s_0}^{s} ds' n_{e,th}(s') B_{\parallel}(s')$$

$$RM = \Delta\varphi \lambda^{-2} = (\varphi - \varphi_0)\lambda^{-2}$$

To account for depolarization due the absorption and Faraday effects, etc., we solve the polarized radiative transfer (PRT) equations with Stokes parameters $[I, Q, U, V]$:

$$\frac{d}{ds}\begin{bmatrix} I \\ Q \\ U \\ V \end{bmatrix} = -\begin{bmatrix} k & q & u & v \\ q & k & f & -g \\ u & -f & k & h \\ v & g & -h & k \end{bmatrix} \begin{bmatrix} I \\ Q \\ U \\ V \end{bmatrix} + \begin{bmatrix} \epsilon_I \\ \epsilon_Q \\ \epsilon_U \\ \epsilon_V \end{bmatrix} \qquad DOLP = \frac{\sqrt{Q^2 + U^2}}{I}$$

*Transfer coefficients* *emission*

## Cluster Simulation

1. MHD simulation using Flash code
2. Infalling subcluster with mass ratio 5:1
3. Initial tangled magnetic field with power law spectrum
4. Initial plasma beta $\beta = {}^{p_{gas}}/_{p_{magnetic}} = 100$

## Conclusions

1. RM enhancement occurs behind a shock front, and a local RM decrement is seen near the cluster center, likely due to turbulence-induced tangled magnetic fields on smaller scales.
2. Using polarized radiative transfer (PRT) calculations, we find that uniform background light is more depolarized near the cluster center, with this effect becoming more pronounced as background intensity decreases.

## RM signatures due to shocks

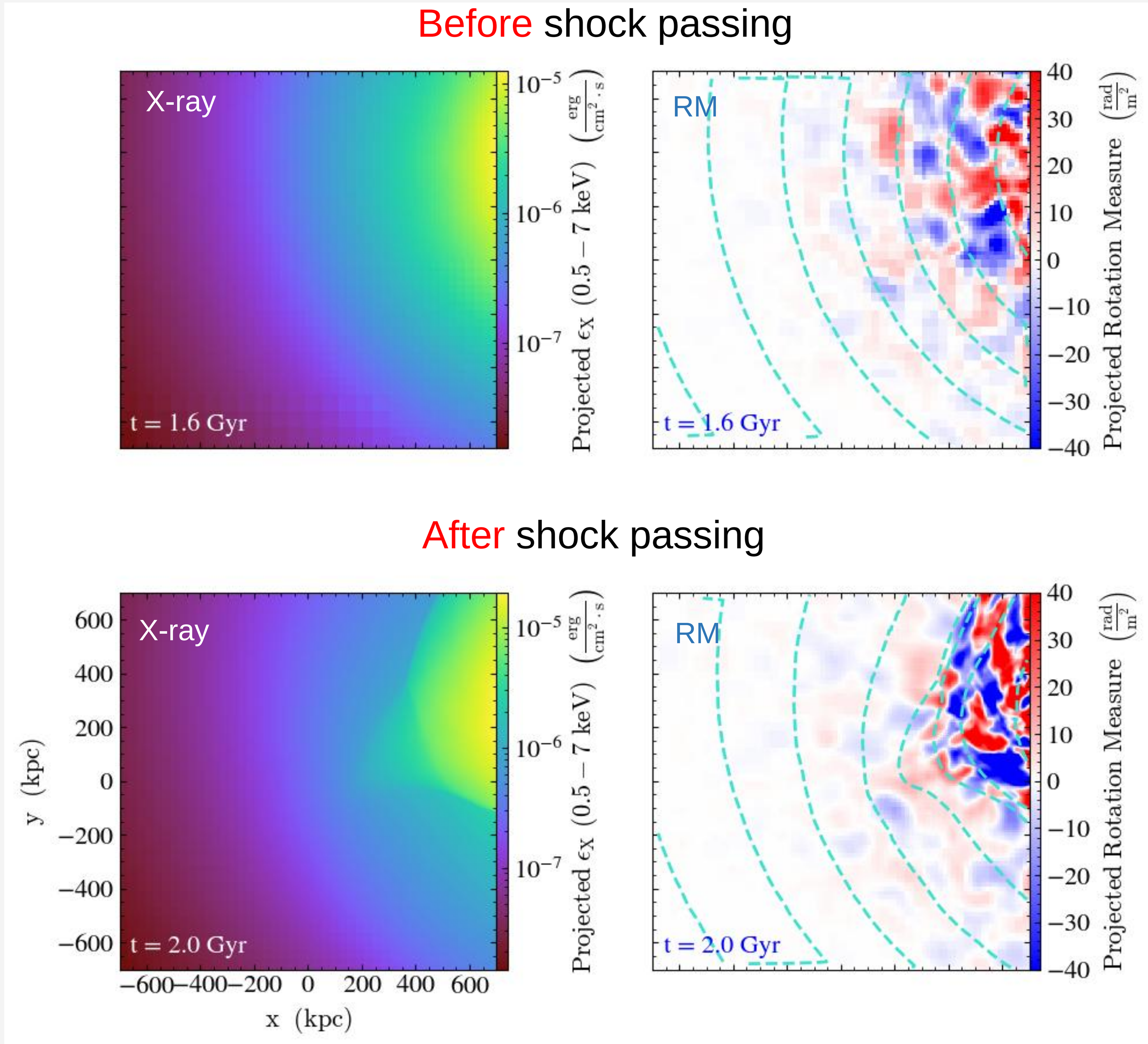



Figure 2. Projected x-ray and RM zoomed in at the shock front at 1.6 Gyr and at 2 Gyr. There's RM enhancement behind shock front and no apparent depolarization region.

## RM signature due to sloshing

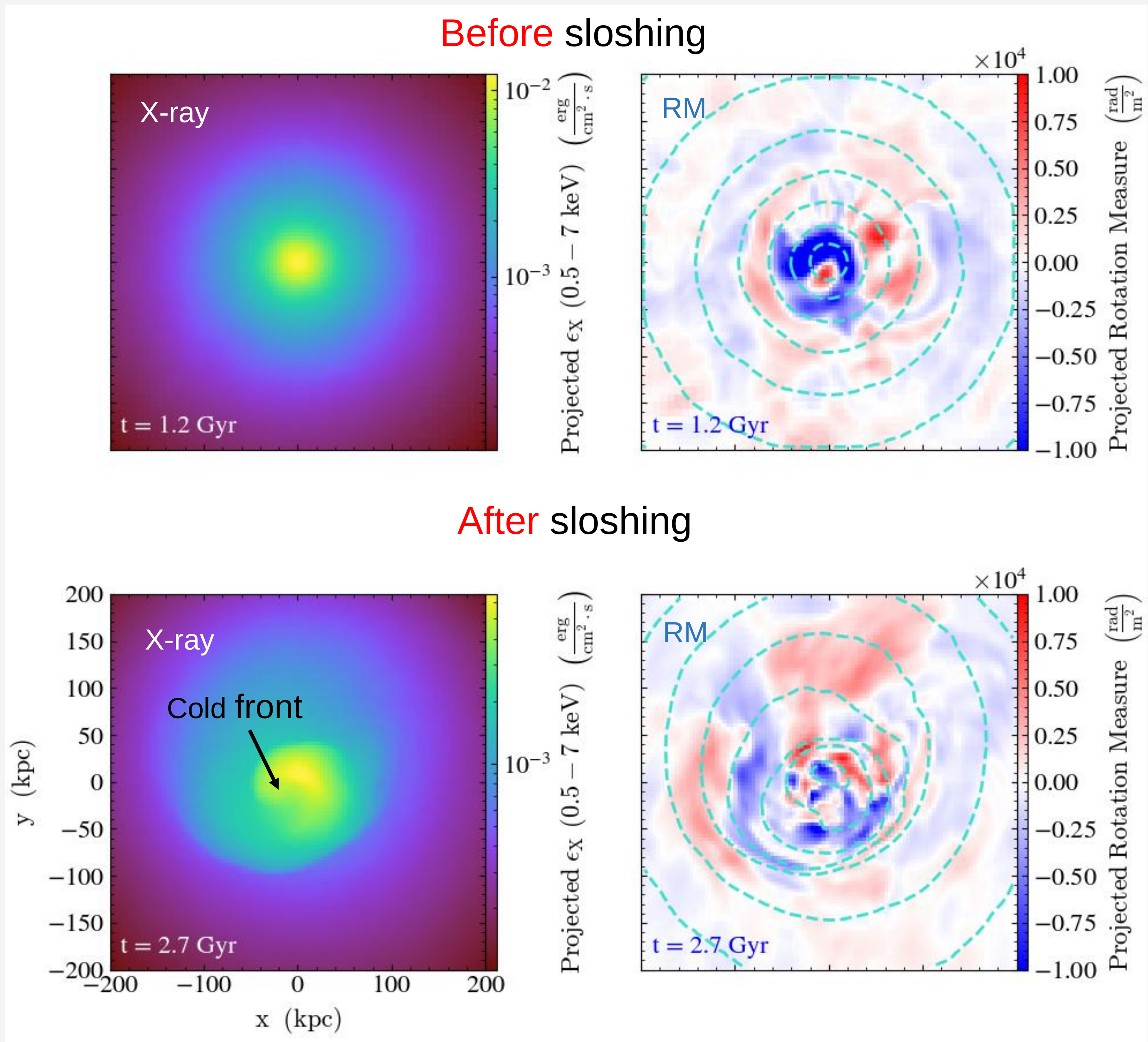



Figure 3. Projected x-ray and RM near cluster center at 1.2 Gyr and at 2.7 Gyr. RM magnitude decreases locally after sloshing (depolarization)

## Depolarization in PRT calculations

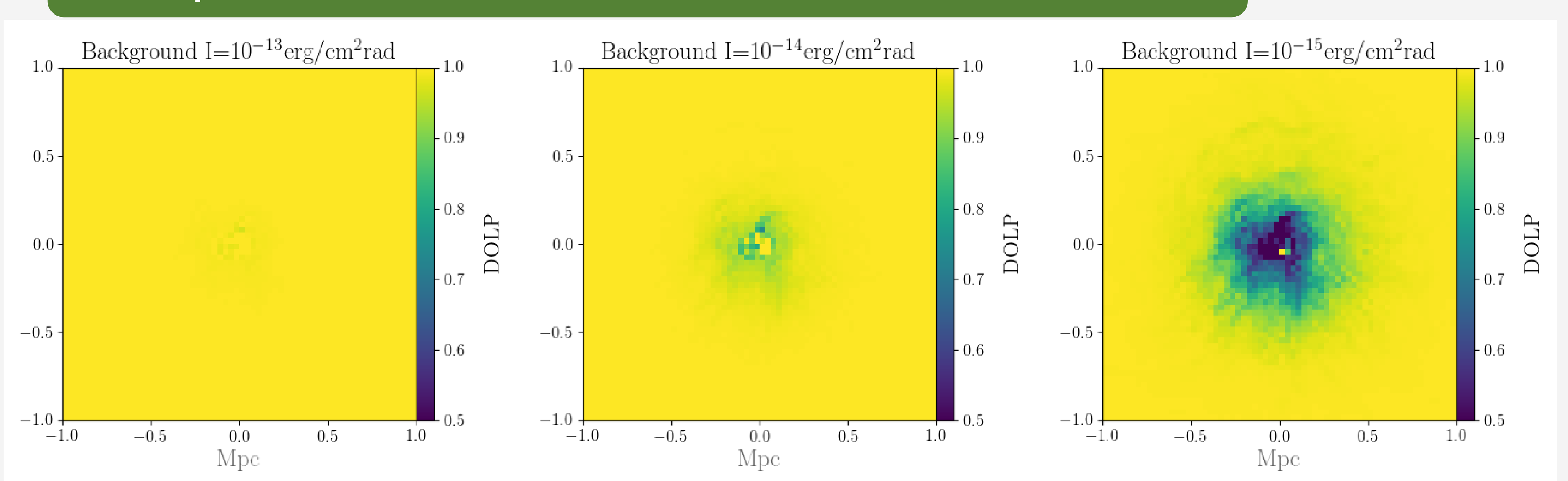



Figure 4. DOLP maps solved by the PRT code, focusing on the sloshing center. From left to right, the initial background intensity $I$ are respectively $(10^{-13}, 10^{-14}, 10^{-15})$ with 100% DOLP. Depolarization occurs when background intensity (with DOLP=1) is comparable or dimmer than the emission of the ICM ($\sim 10^{-15}$).

## References

1. Dubey et al. (2009)
2. Chan et al. (2019)
3. On et al. (2019)
4. Anderson et al (2021)