



Diffuse Radio Emission and Weak X-ray Shocks in Galaxy Clusters

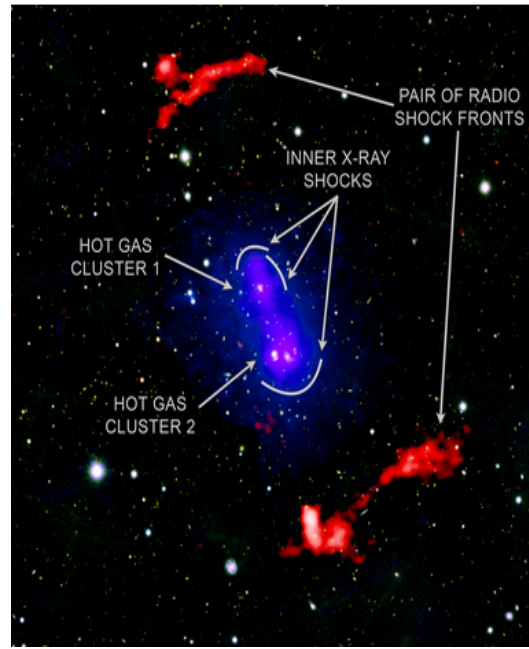


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Scientific Motivation

Diffuse radio emission in galaxy clusters is associated with merger shocks that accelerate relativistic particles in the intracluster medium (ICM). Radio relics are typically produced in shocks with $M \gtrsim 2$, but X-ray observations reveal much weaker shocks ($M_X \sim 1.2 - 1.6$), e.g. in the Perseus cluster.



Despite their low strength, diffuse radio emission is still observed near these shocks.

Key Question: Can weak shocks efficiently re-accelerate relativistic (fossil) electrons?

Introduction

Galaxy clusters are the largest gravitationally bound structures in the Universe and contain a hot plasma known as the intracluster medium (ICM). Cluster mergers generate shock waves that propagate through the ICM and compress the gas. These shocks can accelerate particles to relativistic energies and produce large-scale diffuse radio emission such as radio halos and radio relics. However, A significant number of X-ray observations reveal shocks strength that are relatively weak, raising questions about their efficiency for particle acceleration.

Research Objectives

- Analyzing shock strength from X-ray data.
- Explore whether weak shocks can contribute to particle acceleration or re-acceleration.

Physics of X-ray Shocks

Shock waves propagate through the hot intracluster medium, compressing and heating the gas. $M = \frac{v_{\text{shock}}}{c_s}$ where v_{shock} is the shock velocity and c_s is the sound speed. The density compression ratio across a shock is $C = \frac{n_2}{n_1}$ Using the Rankine-Hugoniot relations

$$M_X = \sqrt{\frac{2C}{\gamma+1-C(\gamma-1)}} \text{ with } \gamma = 5/3.$$

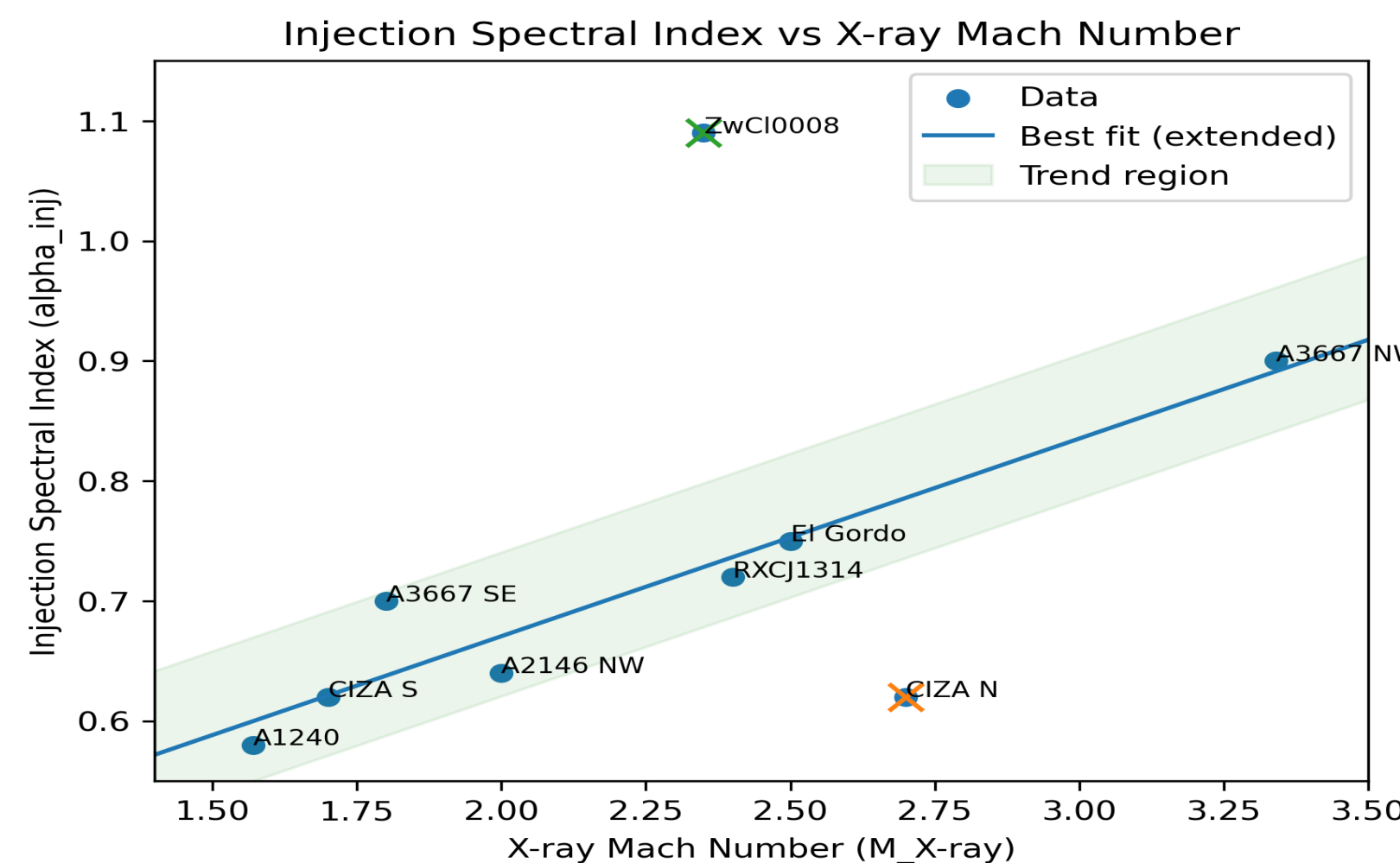
Methodology

- A sample of galaxy clusters with X-ray detected shocks associated with radio relics was compiled from published literature.
- Shock strength analyzed using Mach numbers derived from X-ray temperature and density jumps.
- Comparison plot constructed between Mach number and spectral index.

Cluster Sample

Cluster	Relic	M_{500}	$M_X(T)$	$M_X(\rho)$	α_{int}
Abell 3667	NW	6.3	3.34	0.5	1.4
CIZA J2242.8+5301	N	10.4	2.7	-	1.12
PSZ2 G323.68+36.14	N	6.2	2.7	-	-
El Gordo	NW	17.0	2.5	2.78	1.25
RXC J1314.4-2515	W	8.7	2.4	1.7	1.22
ZwCl 0008.8+5215	W	4.8	2.35	1.48	1.59
Abell 2146	NW	6.8	2.0	1.6	1.14
Abell 3667	SE	6.3	1.8	1.3	1.20
Abell 2146	SE	6.8	1.8	1.3	1.14
CIZA J2242.8+5301	S	10.4	1.7	-	1.12
Abell 1240	NW	5.1	1.57	2.0	1.08
ZwCl 2341.1+0000	NW	5.3	-	2.06	-
ZwCl 2341.1+0000	SE	5.3	-	1.43	-

Mach Number vs Spectral Index



Test Case: Perseus Cluster

- Diffuse emission on large scales
- Evidence for re-acceleration
- Weak shocks present
- Hints of Radio Relics

Results & Discussion

- A weak positive correlation is observed between X-ray Mach number (M_X) and injection spectral index (α_{inj}).
- The best-fit relation from the graph shows that:

$$\alpha_{inj} \propto 0.18 M_X$$

- Significant scatter is present, indicating that Mach number alone does not fully determine particle acceleration efficiency.
- Several low Mach number shocks ($M_X \sim 1.5 - 2.0$) are associated with detectable radio emission.
- Outliers suggest additional physical processes, such as fossil electron re-acceleration and magnetic field effects.

Conclusions

Weak shocks are common but are inefficient for direct acceleration, but can contribute to radio emission through re-acceleration mechanisms.

References

Akamatsu & Kawahara (2013); van Weeren et al(2019).; Botteon et al(2020).; Duchesne et al.: J. Graham, A. C. Fabian & J. S. Sanders (2008).; R. J. van Weeren (2024)

Acknowledgement

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