Revealing the ICM transport properties with a deep Chandra observation of Abell 2146

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Chandra image of Abell 2146
Outline

- Intro to galaxy cluster merger shock fronts

Abell 2146: two merger shock fronts

- 400ks Chandra observation
  - Establishment of electron-ion equilibrium
- GMRT 325MHz radio observation
  - Lack of extended radio emission

- Conclusions
Galaxy cluster mergers

- Evidence for dark matter
- Constraints on DM self-interaction cross section
- Intracluster medium transport processes
  - Electron-ion equilibrium, viscosity, conduction, turbulence
- Radio halos, relics + relativistic particle acceleration

*Bullet cluster*, Markevitch 2006, Clowe et al. 2006
Detection of shock fronts

- **Subcluster velocity** in the plane of the sky
- Merger geometry, timescale + evolution

**Bullet cluster**, Markevitch 2006, Clowe et al. 2006

**Abell 520**, Markevitch et al. 2005, Mahdavi et al. 2007
Abell 2146: 400 ks Chandra

- $L_X = 1.6 \times 10^{45}$ erg/s
- $T_X = 6.7$ keV
- redshift 0.23
Deep Chandra observation

X-ray surface brightness

Unsharp masked image
Bow shock:

$\rho_1 / \rho_2 = 2.4 \pm 0.2$
Bow shock:

\[ \frac{\rho_1}{\rho_2} = 2.4 \pm 0.2 \]

\[ M = 2.1 \pm 0.2 \]
Electron-ion equilibration: Bullet

Markevitch 2006
Electron-ion equilibration: A2146
Upstream shock:

\[ \frac{\rho_1}{\rho_2} = 1.8 \pm 0.2 \]
Upstream shock:

\[ \frac{\rho_1}{\rho_2} = 1.8 \pm 0.2 \]

\[ M = 1.6 \pm 0.1 \]
Electron-ion equilibration: A2146
Radio Halos + Relics

- Mpc-scale synchrotron emission associated with cluster mergers

Bullet cluster
Liang et al. 2000

Abell 754
Macario et al. 2010

Abell 521
Giacintucci et al. 2008

Abell 520
Govoni et al. 2001
No extended radio emission

GMRT 325MHz

Russell, van Weeren et al. 2011

Brunetti et al. 2009
Conclusions

- Abell 2146 is undergoing a major merger and has two Mach ~ 2 shock fronts.
- Establishment of electron-ion equilibrium behind the bow shock appears consistent with the collisional timescale.
- No radio relics or radio halo detected in GMRT 325MHz observation.
Abell 2146 Optical

R-band Subaru image: S. Okamoto, L. King
Abell 2146: 45 ks

- $L_X = 1.6 \times 10^{45}$ erg/s
- $T_X = 6.7$ keV
- redshift 0.23

Russell et al. 2010
Galaxy Cluster Mergers

- Shocks – dashed lines
- Cone shape

Markevitch et al. 2000
Rankine-Hugoniot jump conditions

Calculate the shock Mach number

\[ M = \frac{v}{c_s} \]

From the density jump:

\[ M = \left( \frac{2 \rho_2 / \rho_1}{\gamma + 1 - \rho_2 / \rho_1 (\gamma - 1)} \right)^{1/2} \]

Also independently from the temperature jump.

Bullet cluster has shock Mach no. \( M = 3.0 \pm 0.4 \) (4700 km/s)
Upstream shock

- Mass ratio of A2146 merger is around 3:1

Ricker + Sarazin 2001
Location of BCG

- Brightest cluster galaxy located *behind* X-ray peak
Temperature map
Plume structures

Zero impact parameter

Non-zero impact parameter

Poole et al. 2006
Core structures
Core structures

Temperature

Emission measure
IFU observations

- WHT Oasis observations of optical emission lines in the BCG

FOV 10 x 7 arcsec (37 x 26 kpc)
IFU observations

- WHT Oasis observations of optical emission lines in the BCG

FOV 10 x 7 arcsec (37 x 26 kpc)