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

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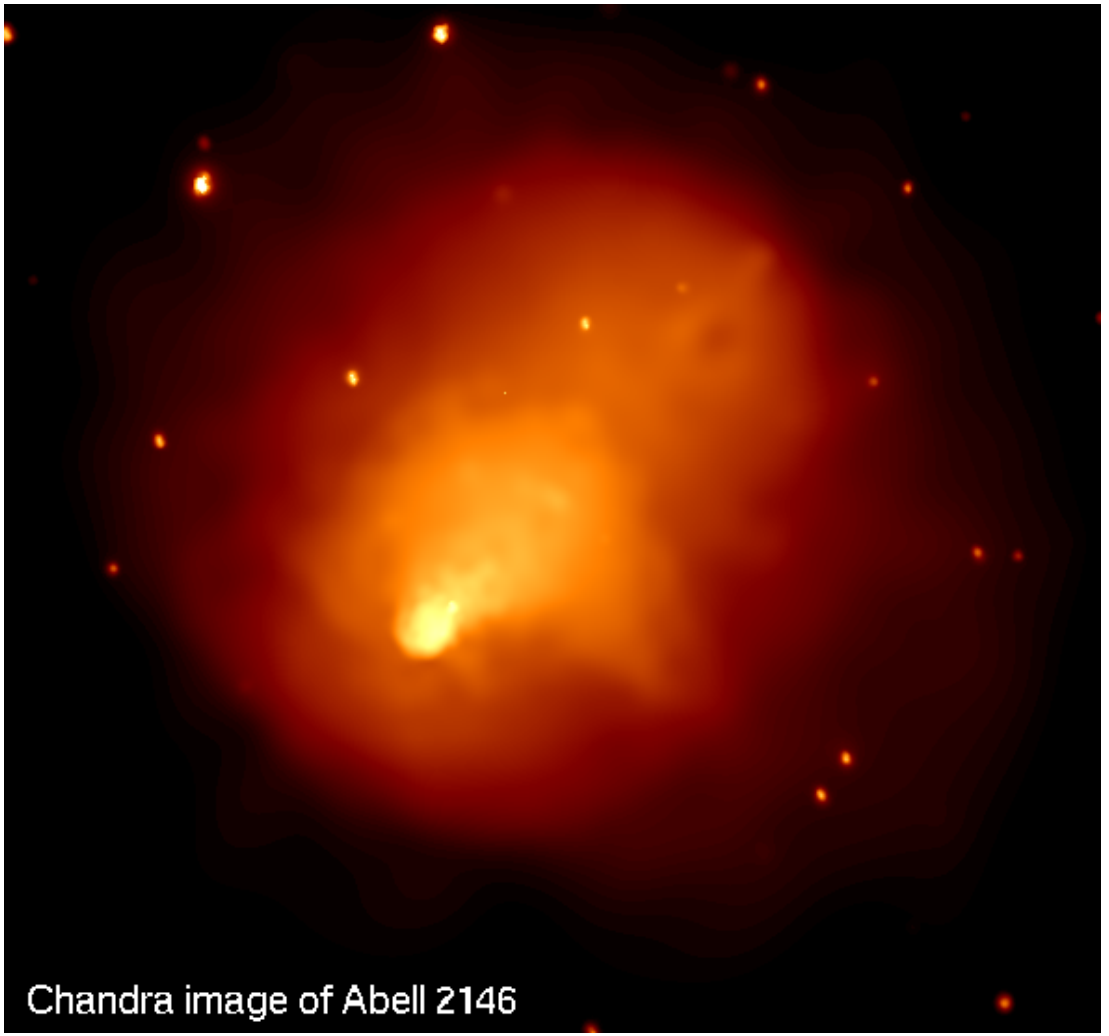

Chandra image of Abell 2146

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

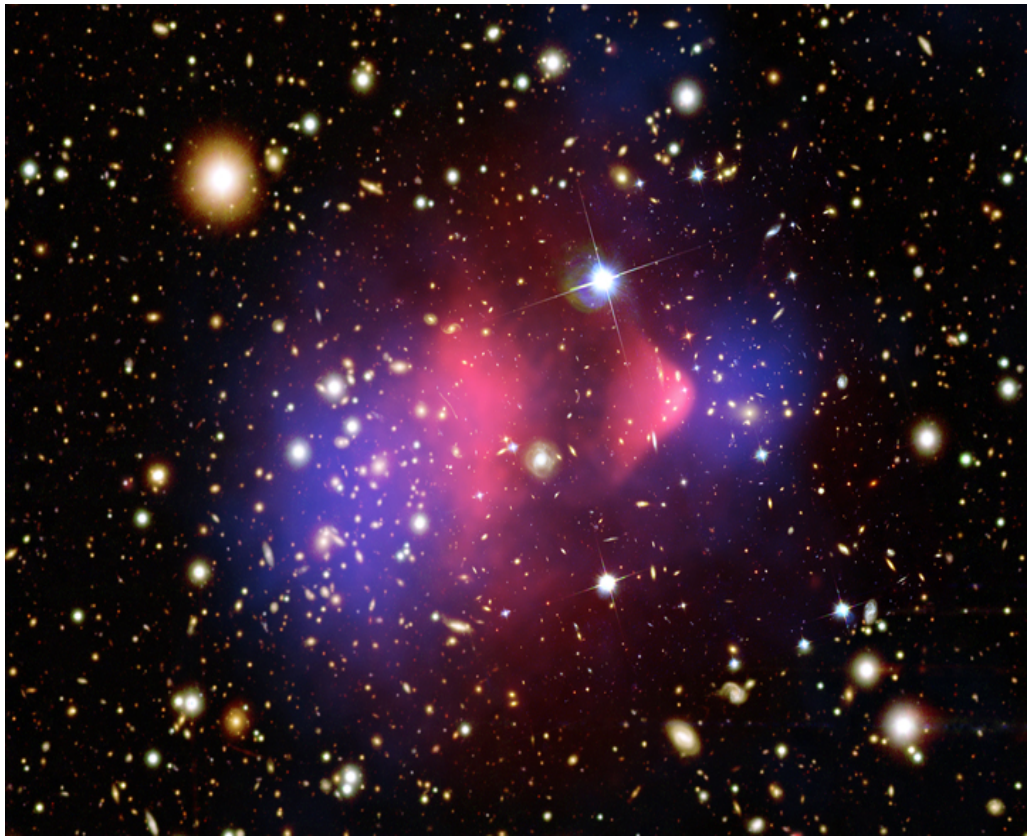
Galaxy cluster mergers

- 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

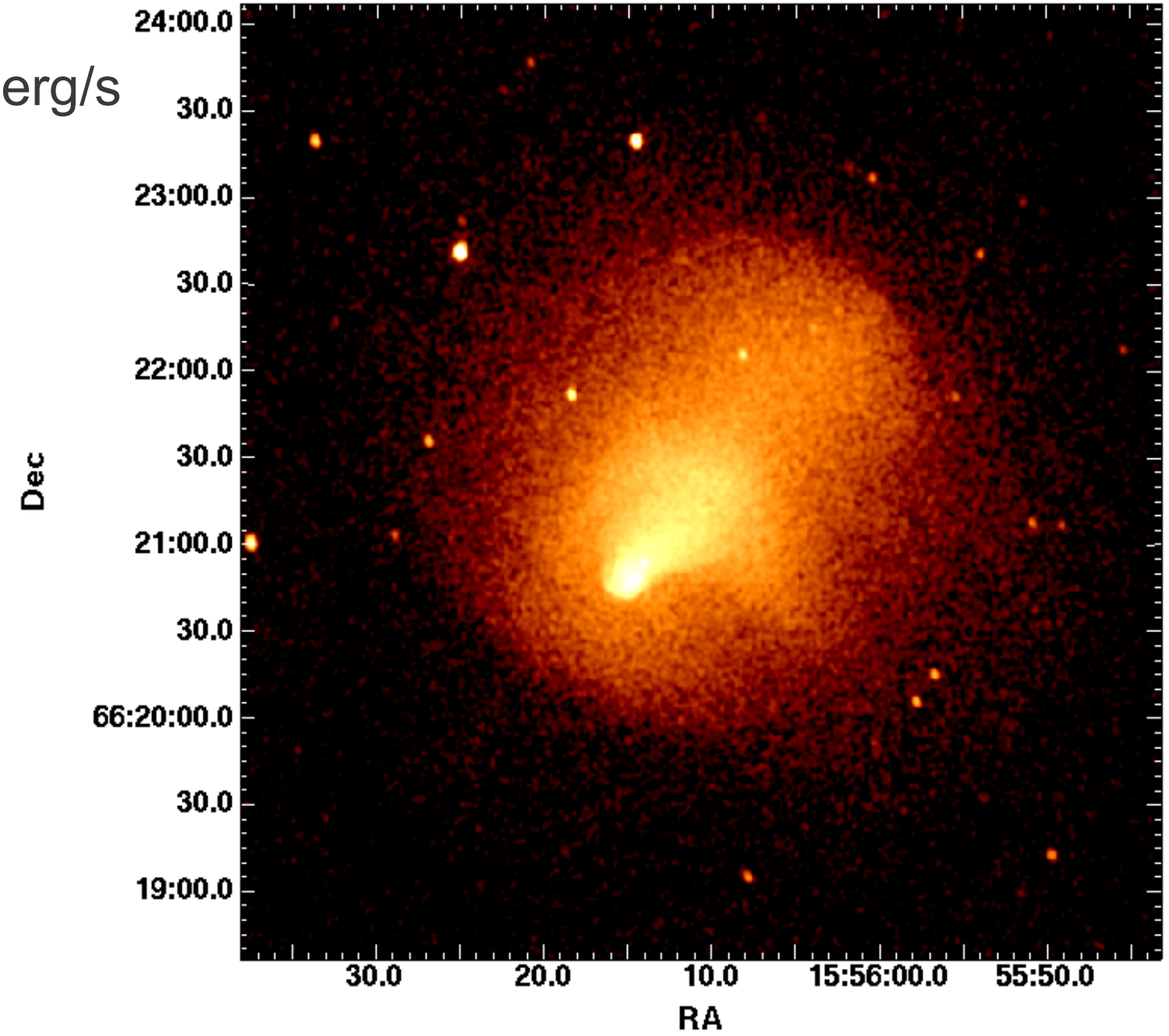


Bullet cluster, Markevitch 2006, Clowe et al. 2006

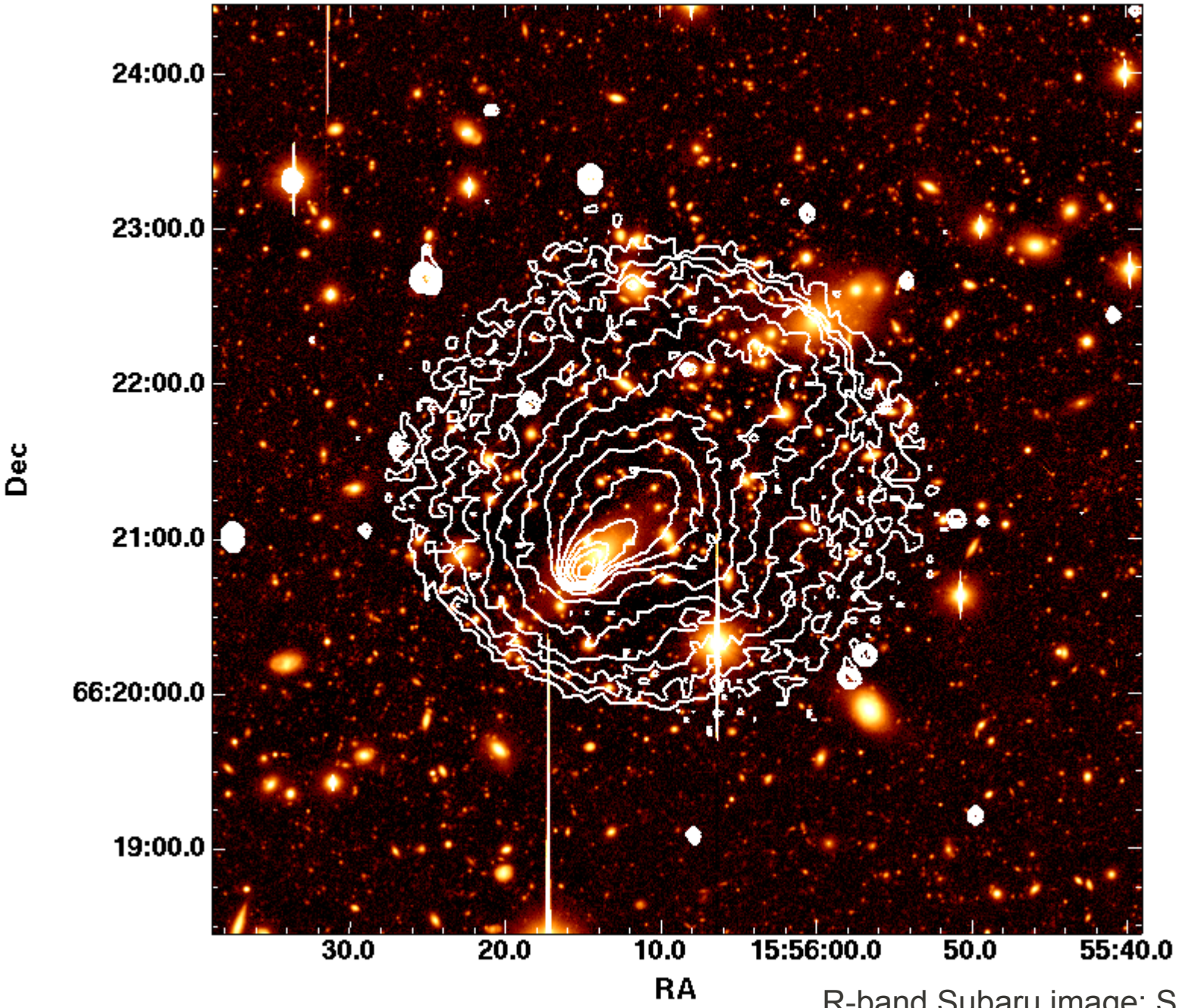
Abell 520, Markevitch et al. 2005, Mahdavi et al. 2007

Abell 2146: 400 ks Chandra

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

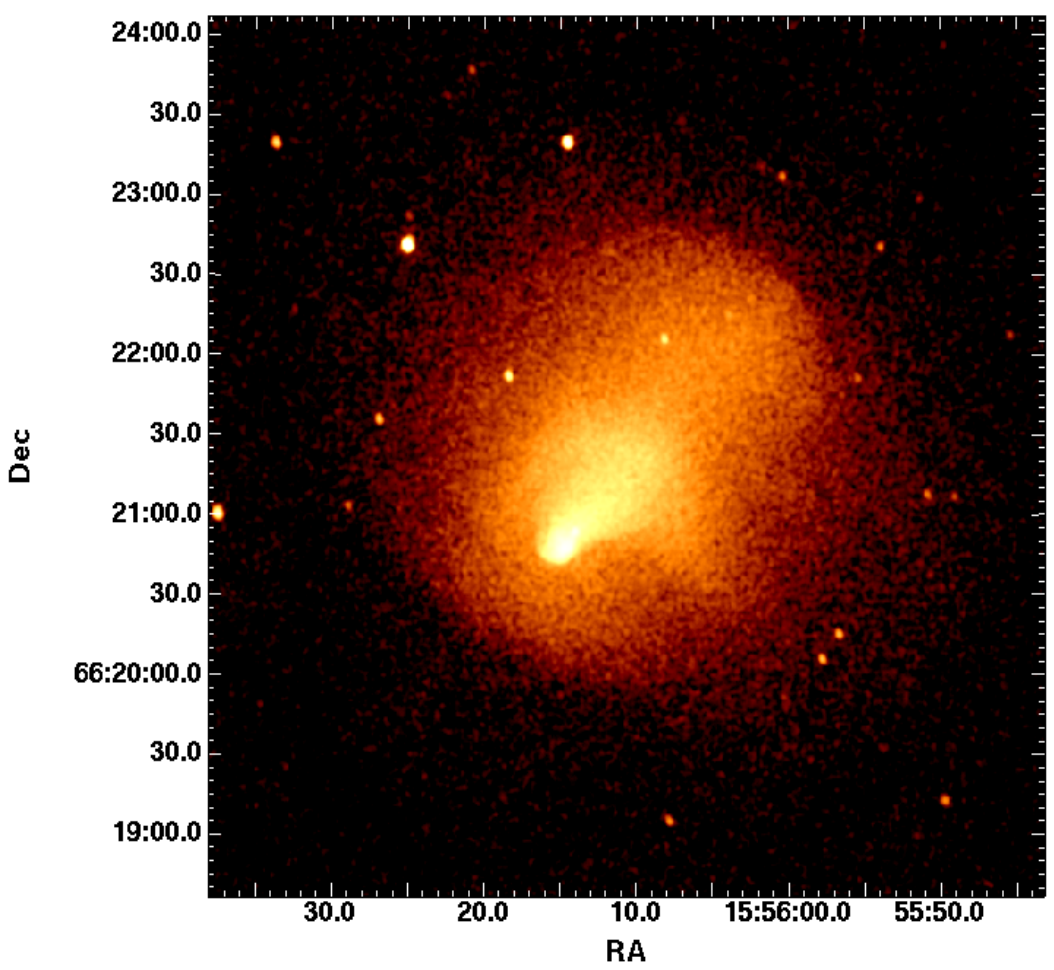


Abell 2146 Optical

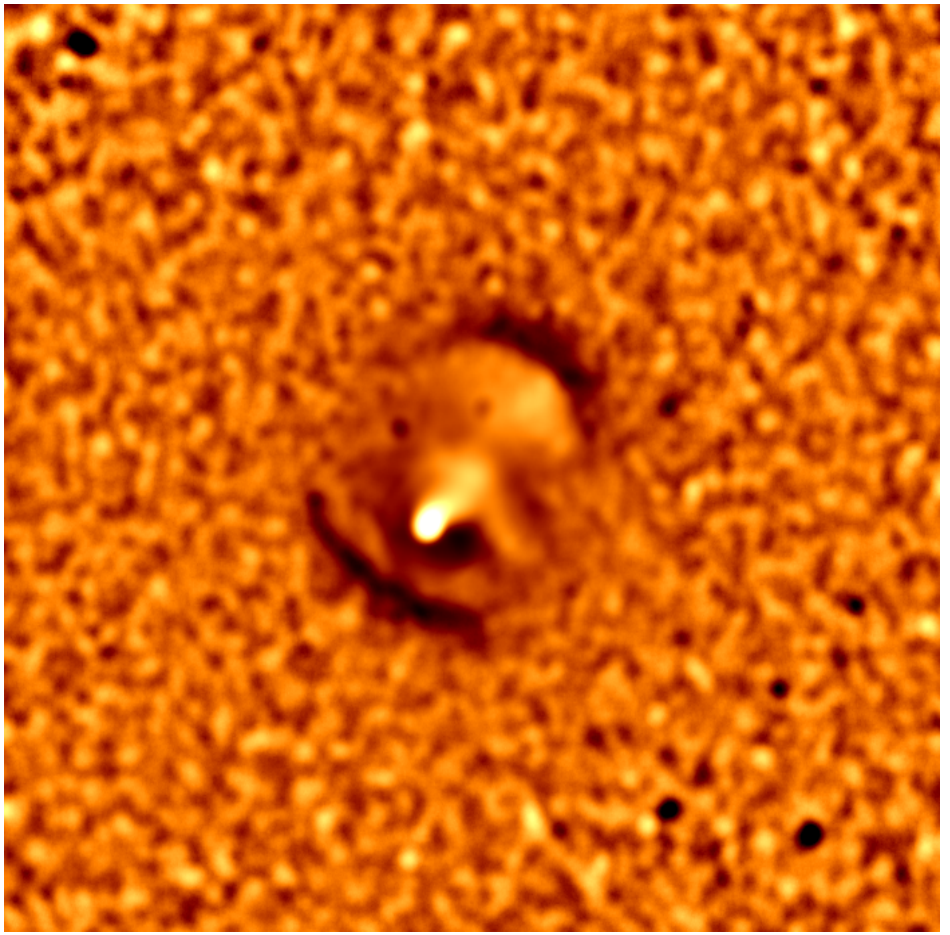


R-band Subaru image: S. Okamoto, L. King

Deep Chandra observation

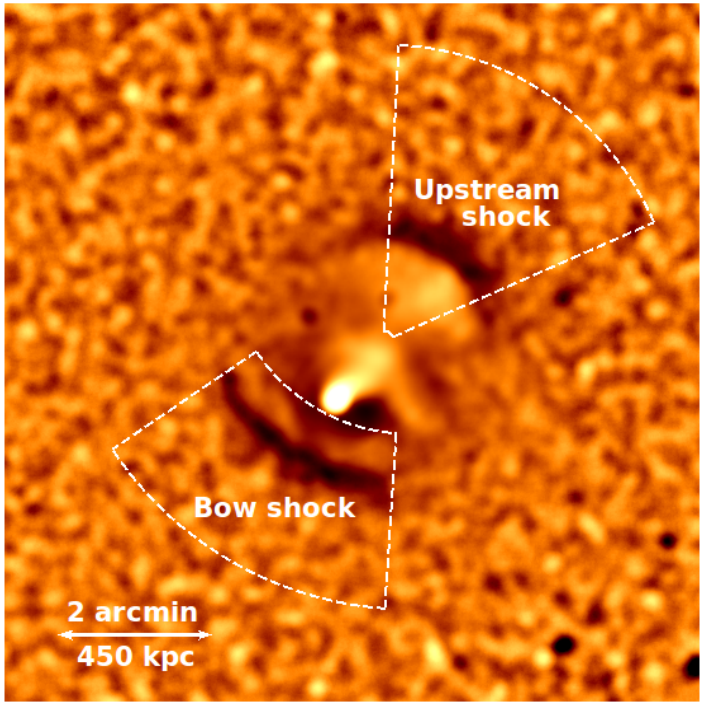


X-ray surface brightness



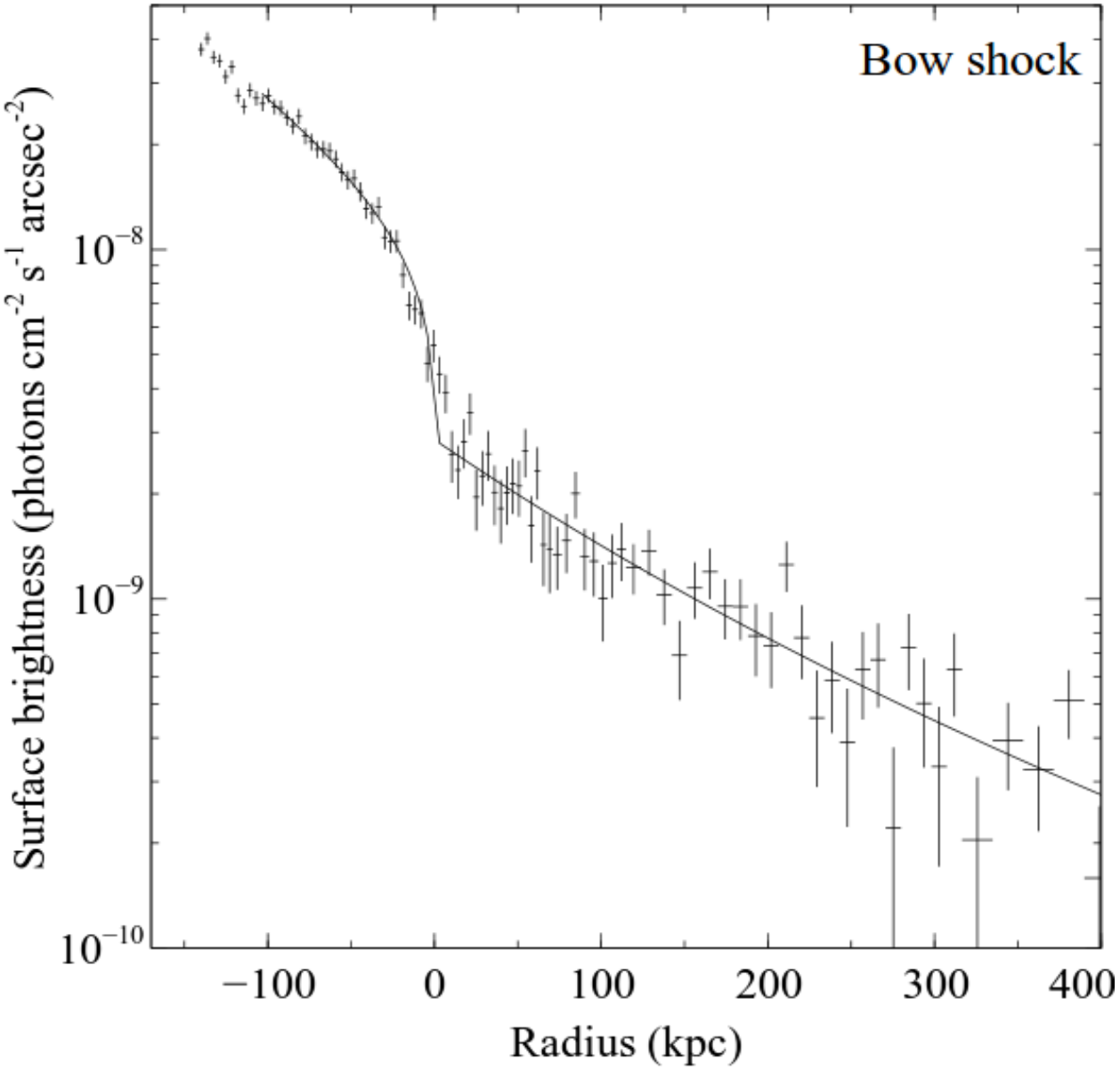
Unsharp masked image

Bow shock

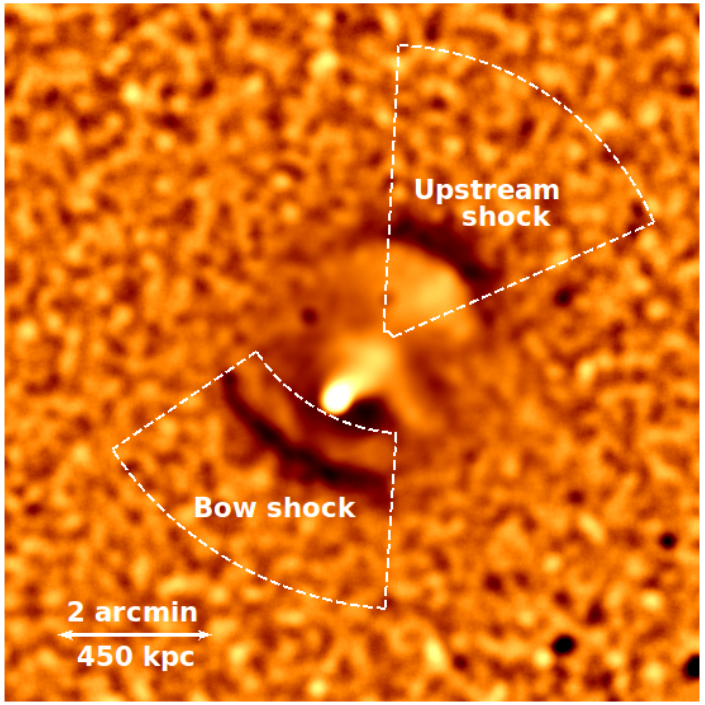


Bow shock:

$\rho_1/\rho_2 = 2.4 \pm 0.2$



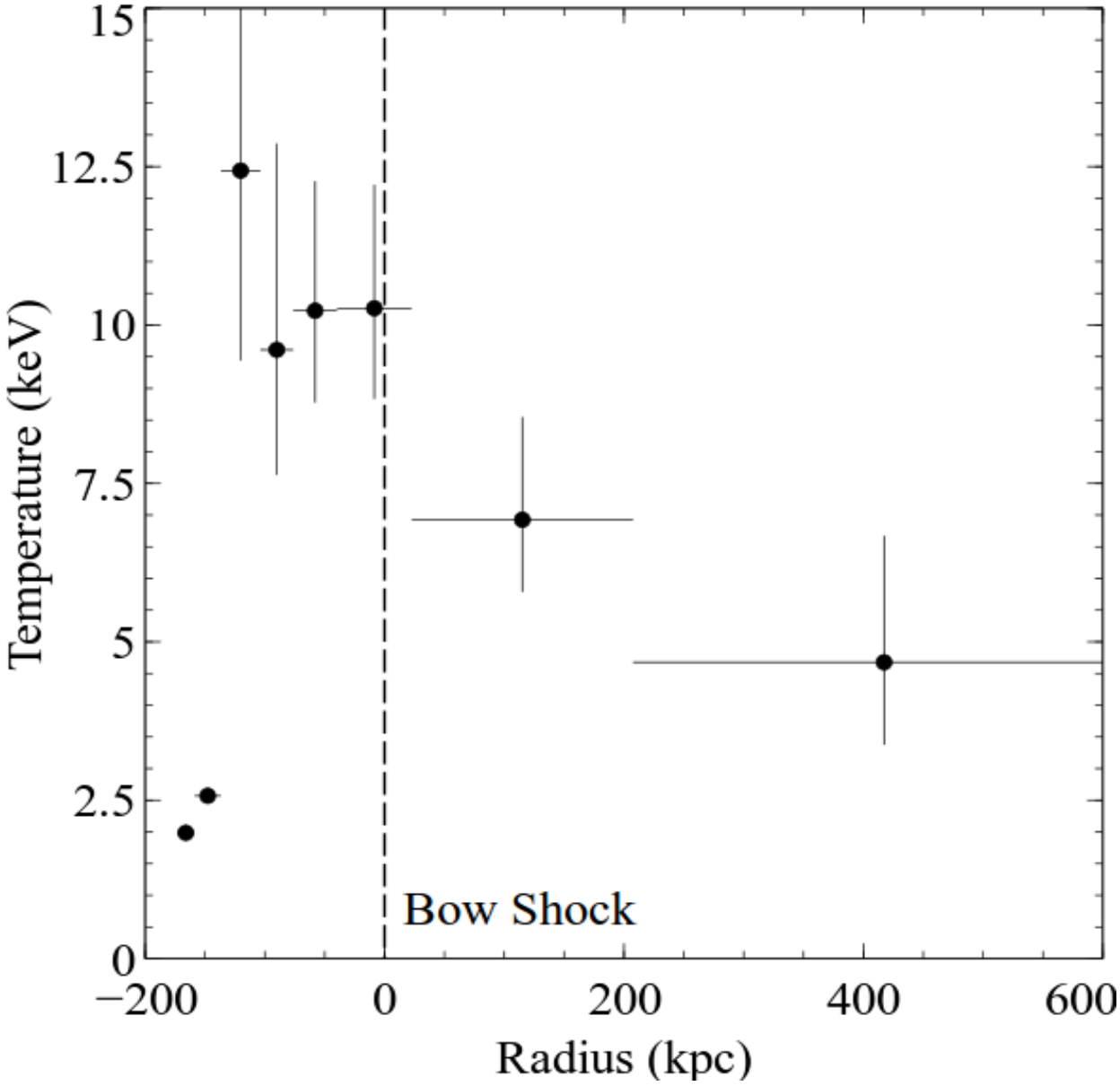
Bow shock



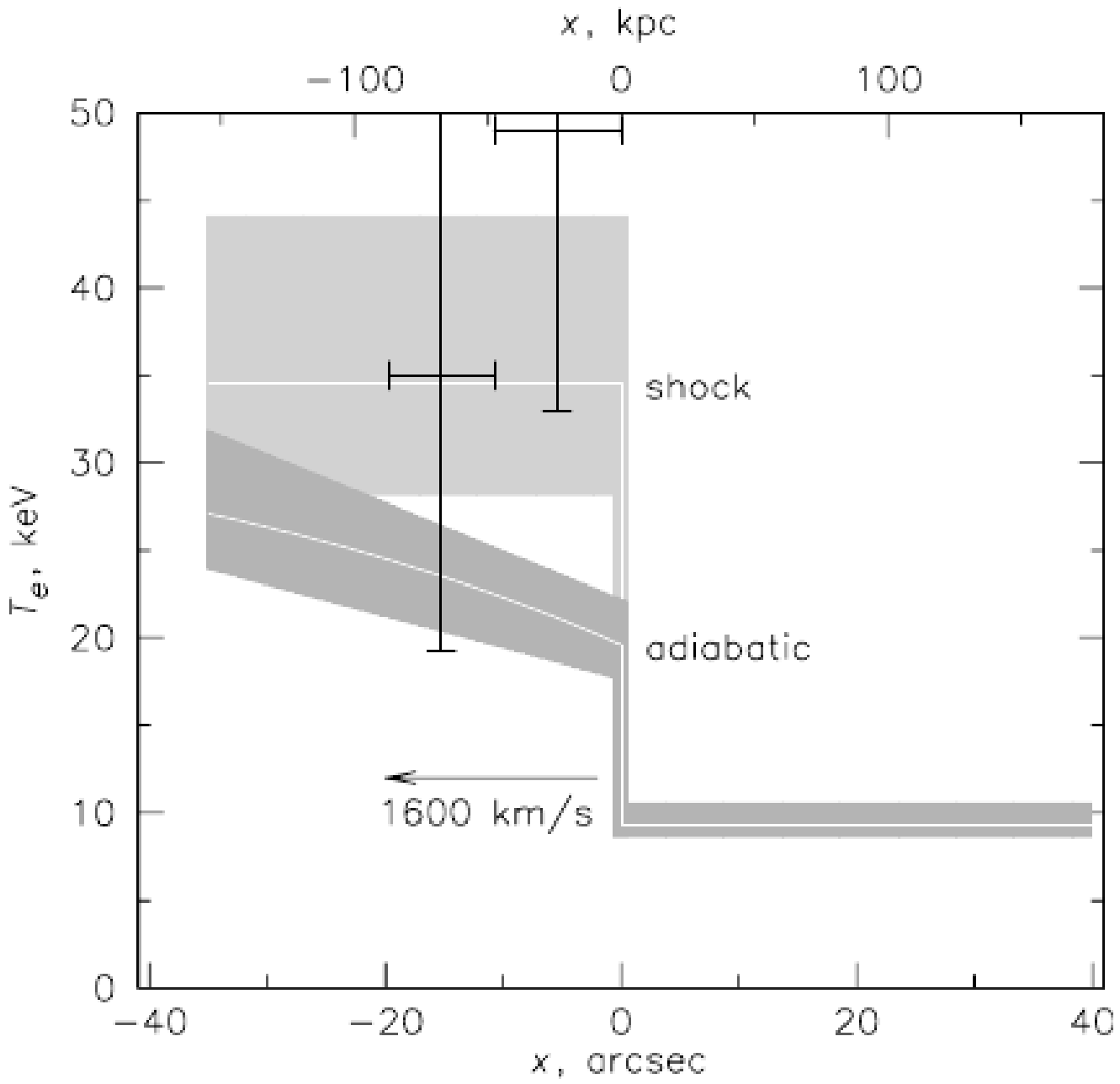
Bow shock:

$\rho_1/\rho_2 = 2.4 \pm 0.2$

$M = 2.1 \pm 0.2$

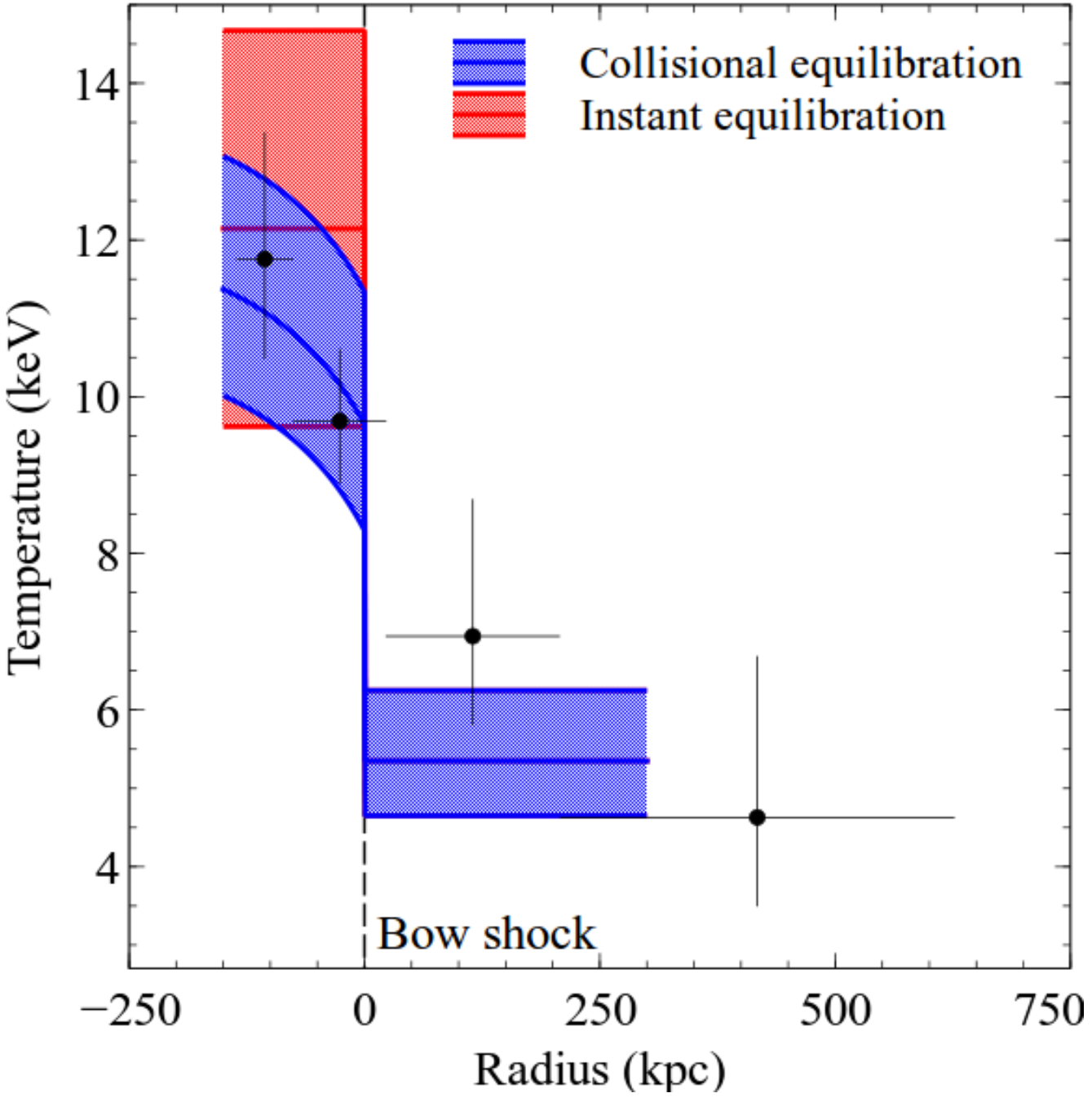


Electron-ion equilibration: Bullet

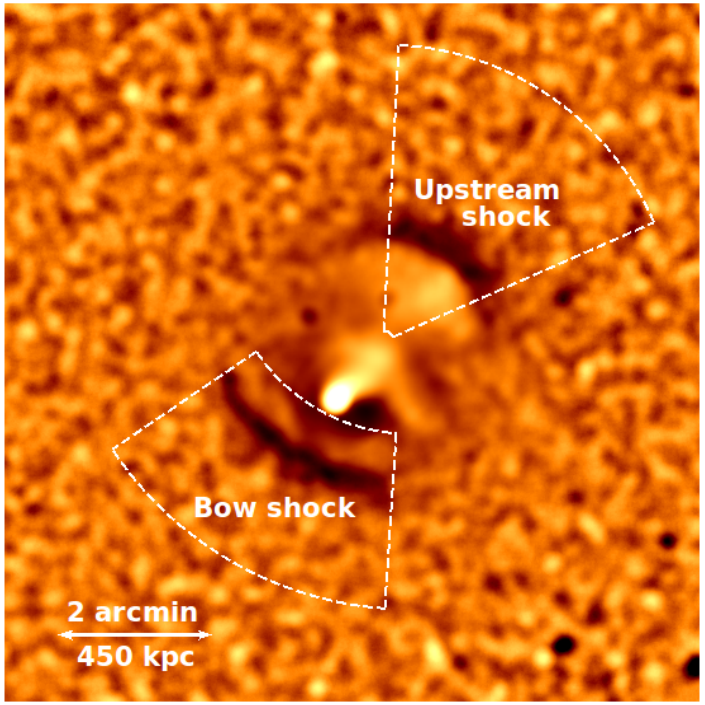


Markevitch 2006

Electron-ion equilibration: A2146

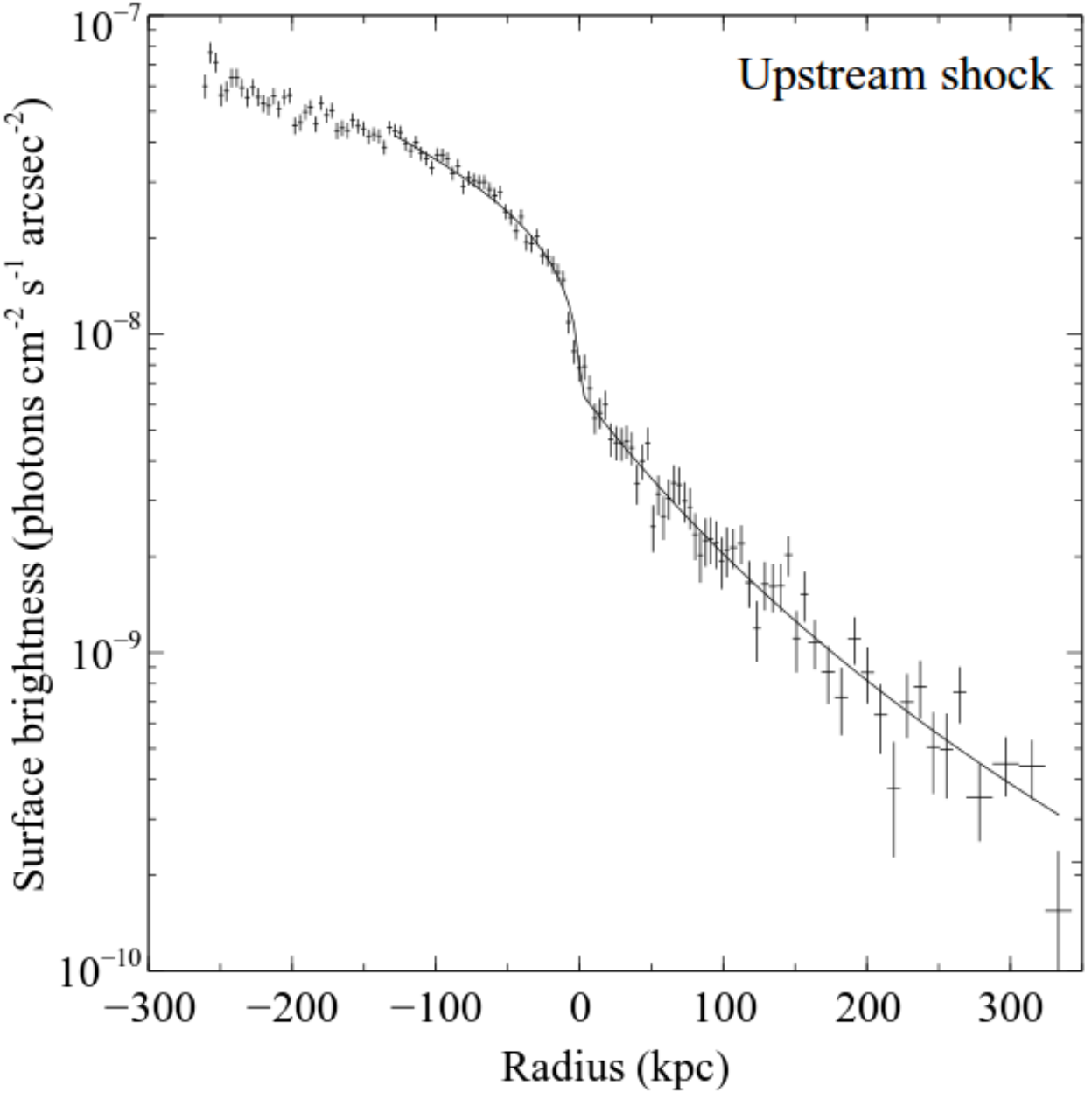


Upstream shock

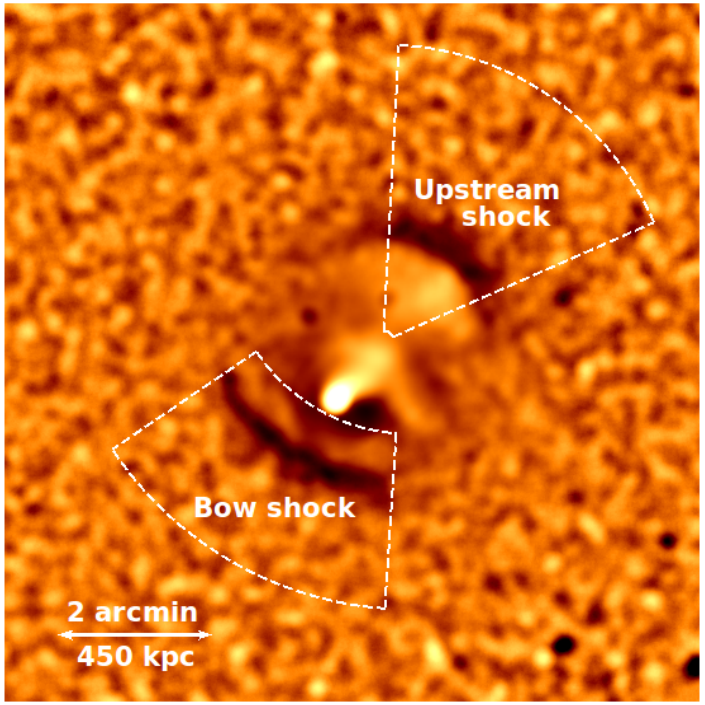


Upstream shock:

$\rho_1/\rho_2 = 1.8 \pm 0.2$



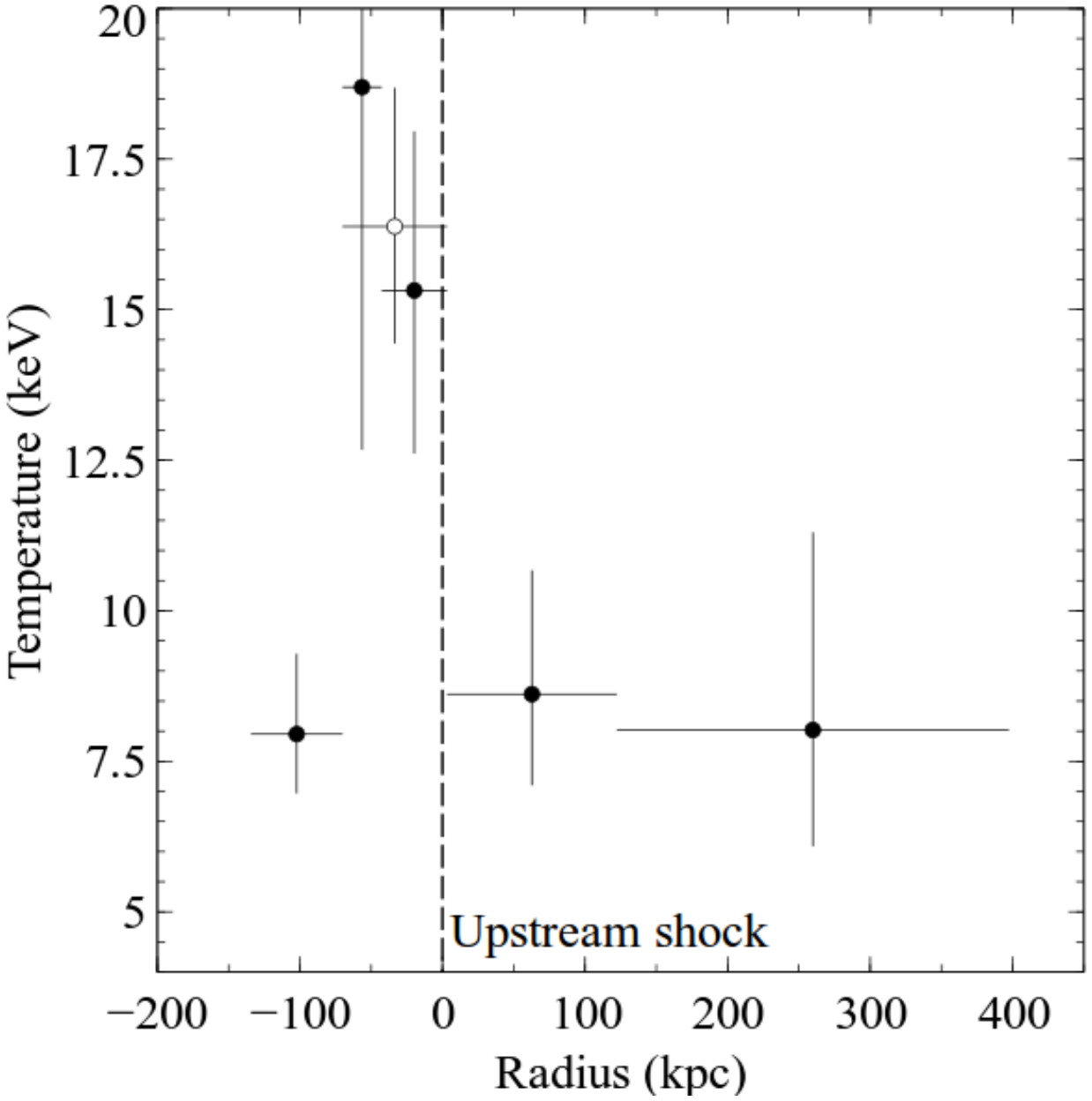
Upstream shock



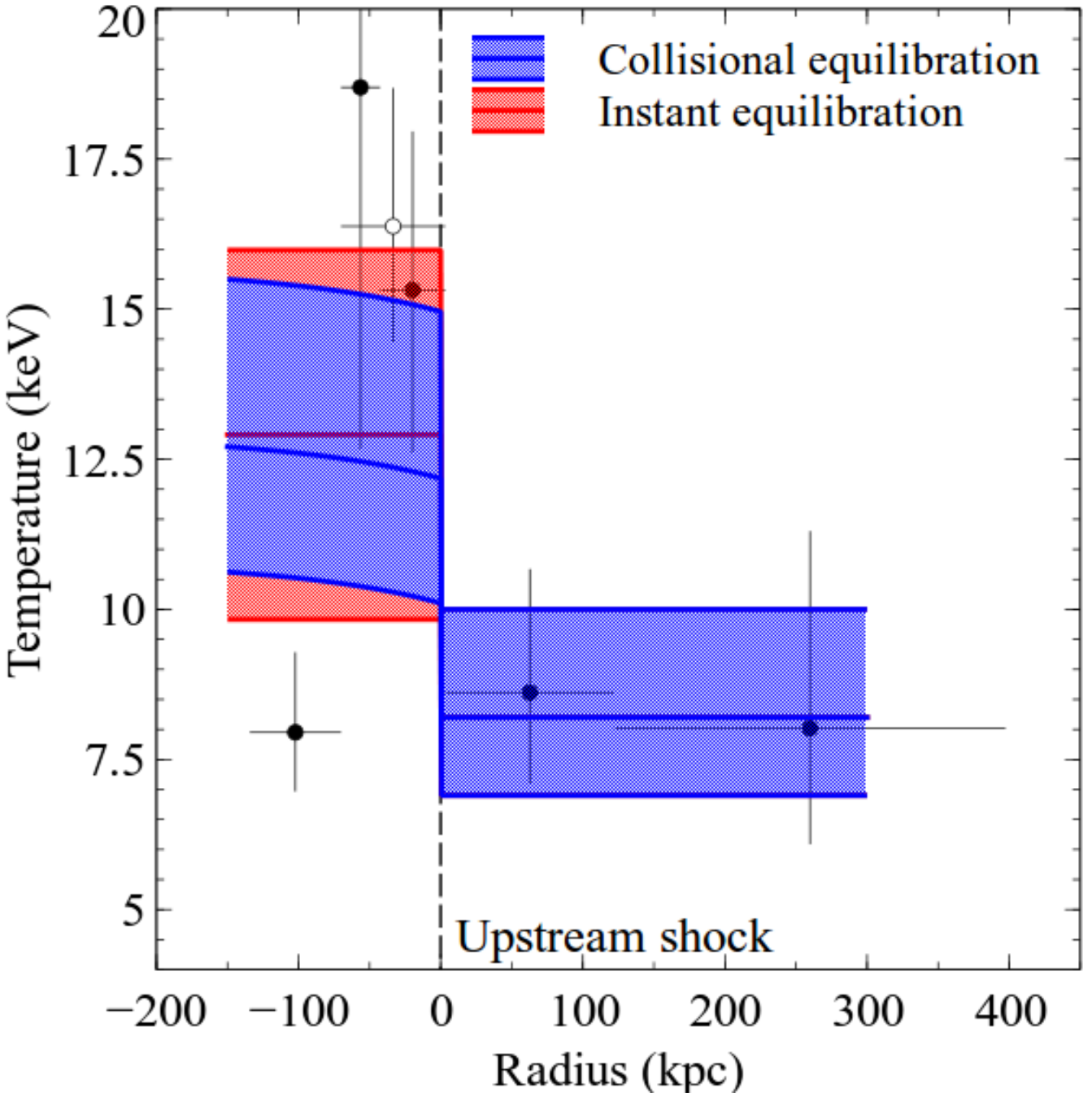
Upstream shock:

$\rho_1/\rho_2 = 1.8 \pm 0.2$

$M = 1.6 \pm 0.1$



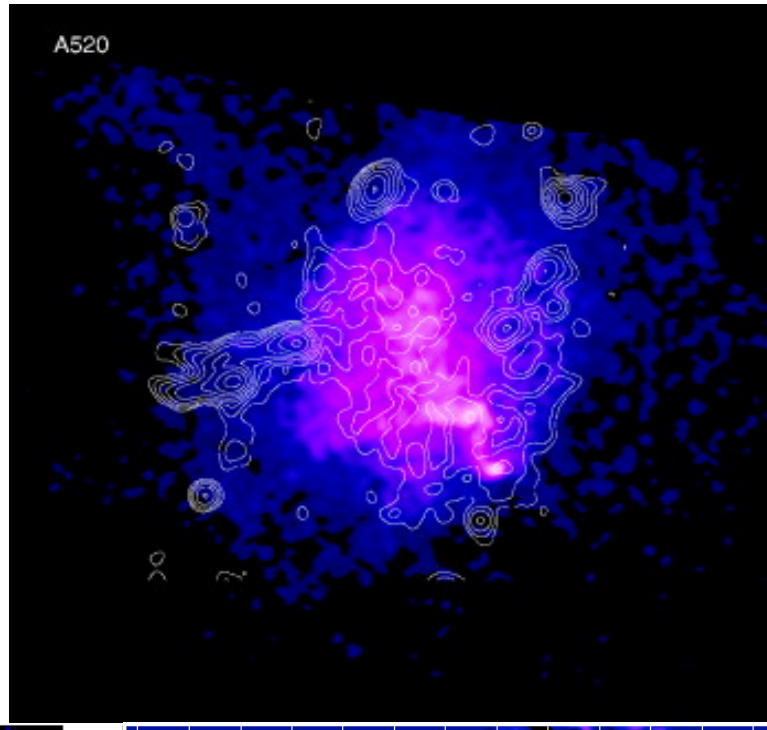
Electron-ion equilibration: A2146



Radio Halos + Relics

- Mpc-scale synchrotron emission associated with cluster mergers

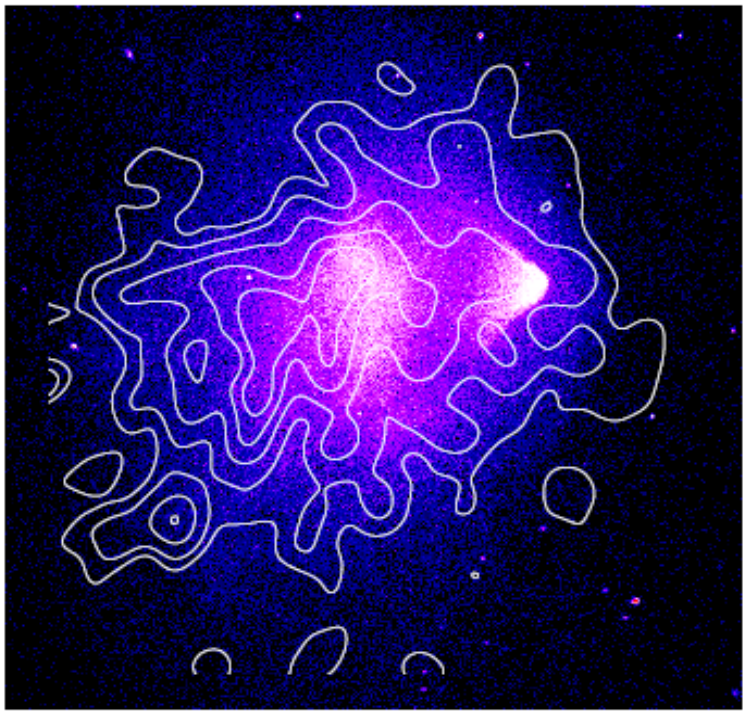
Abell 520
Govoni et al. 2001

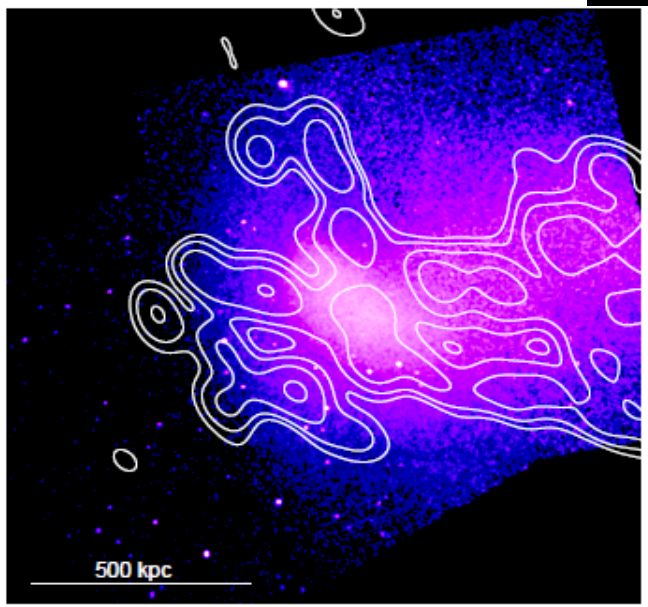


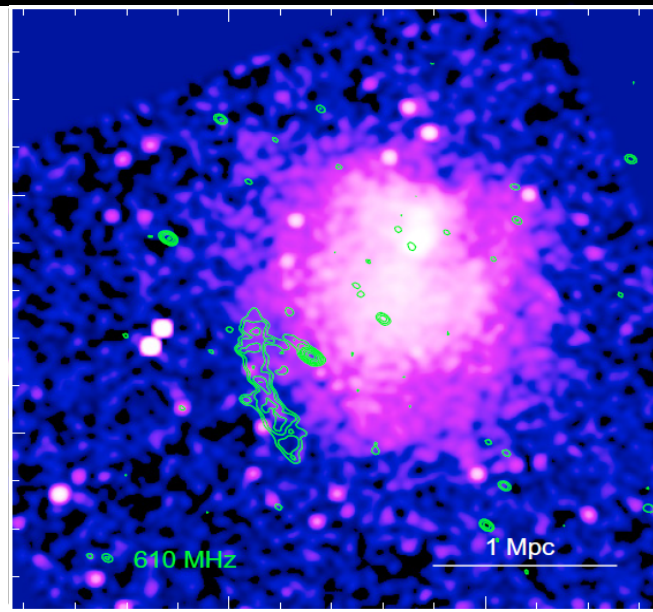
Abell 754
Macario et al. 2010

Abell 521
Giacintucci et al. 2008

Bullet cluster
Liang et al. 2000

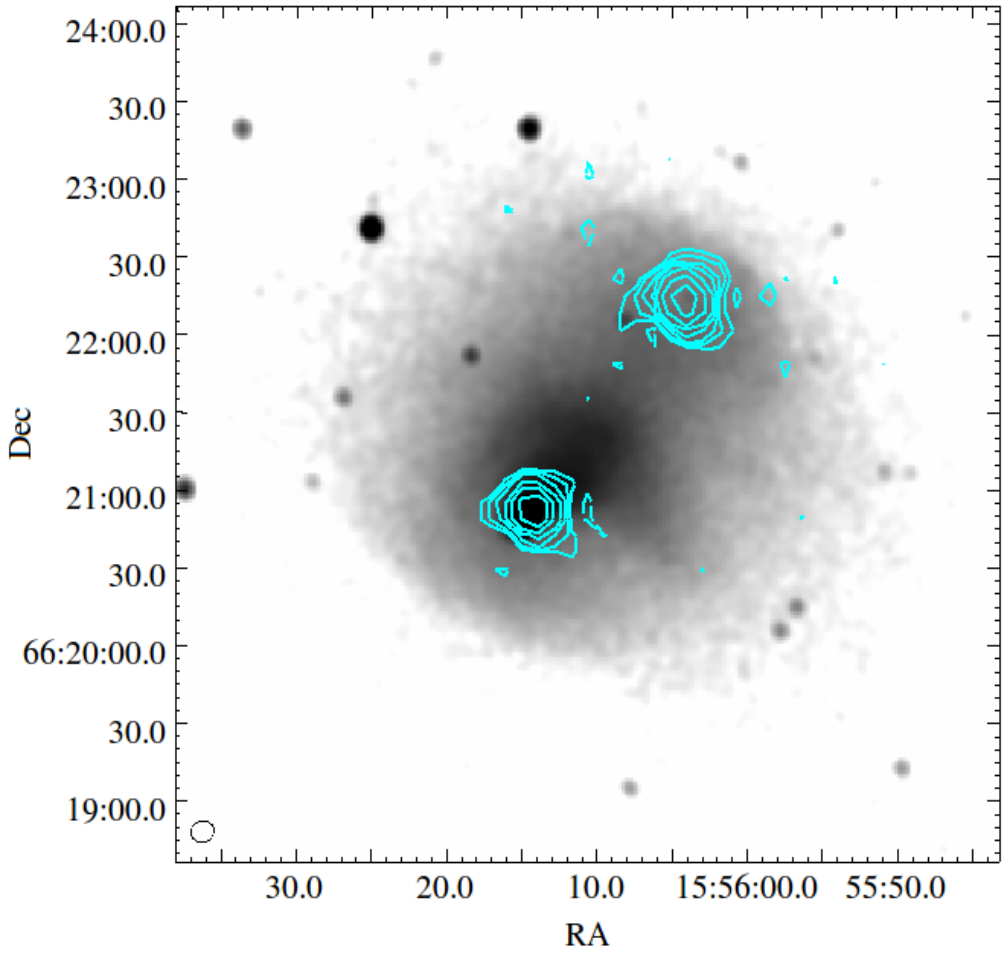




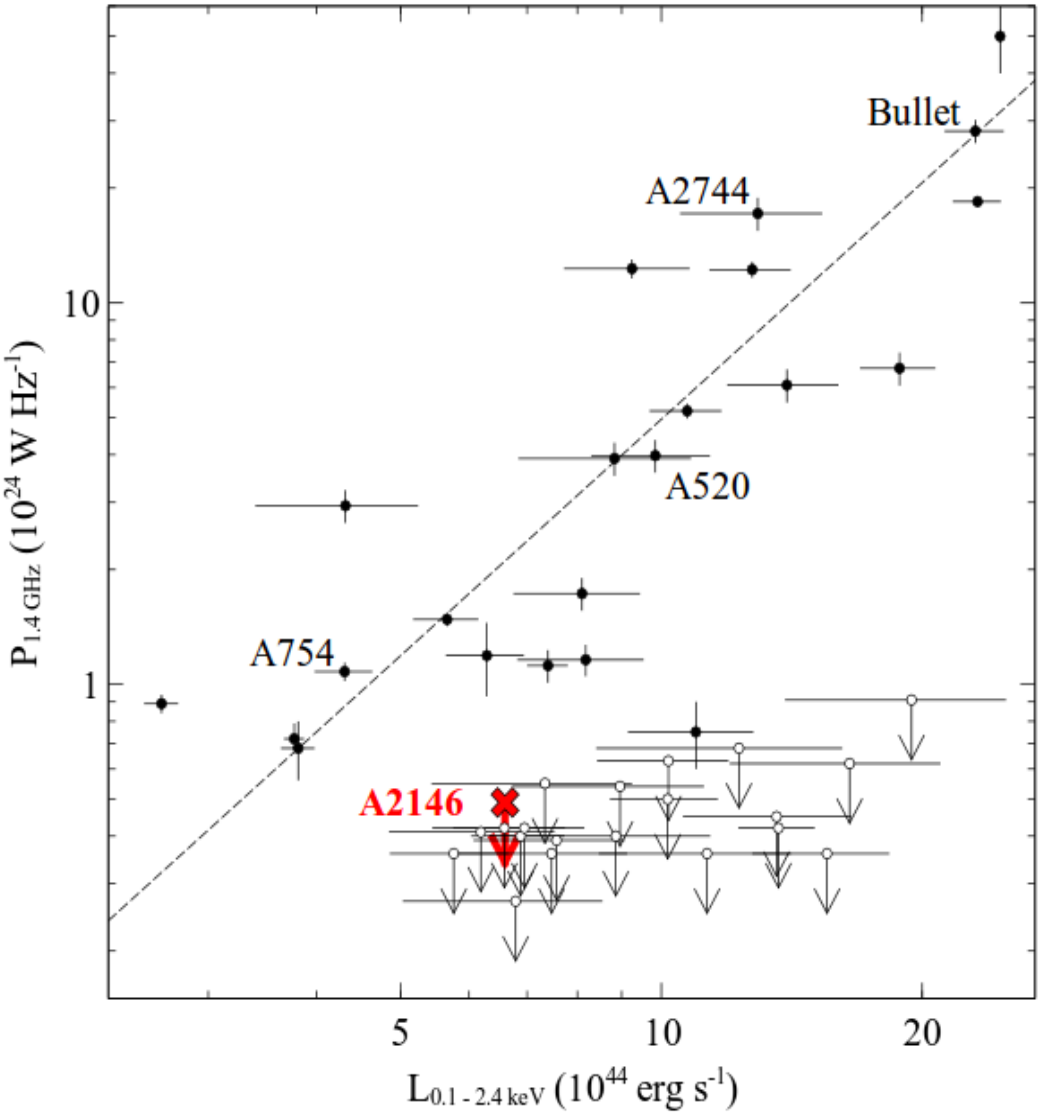


No extended radio emission

GMRT 325MHz



Russell, van Weeren et al. 2011

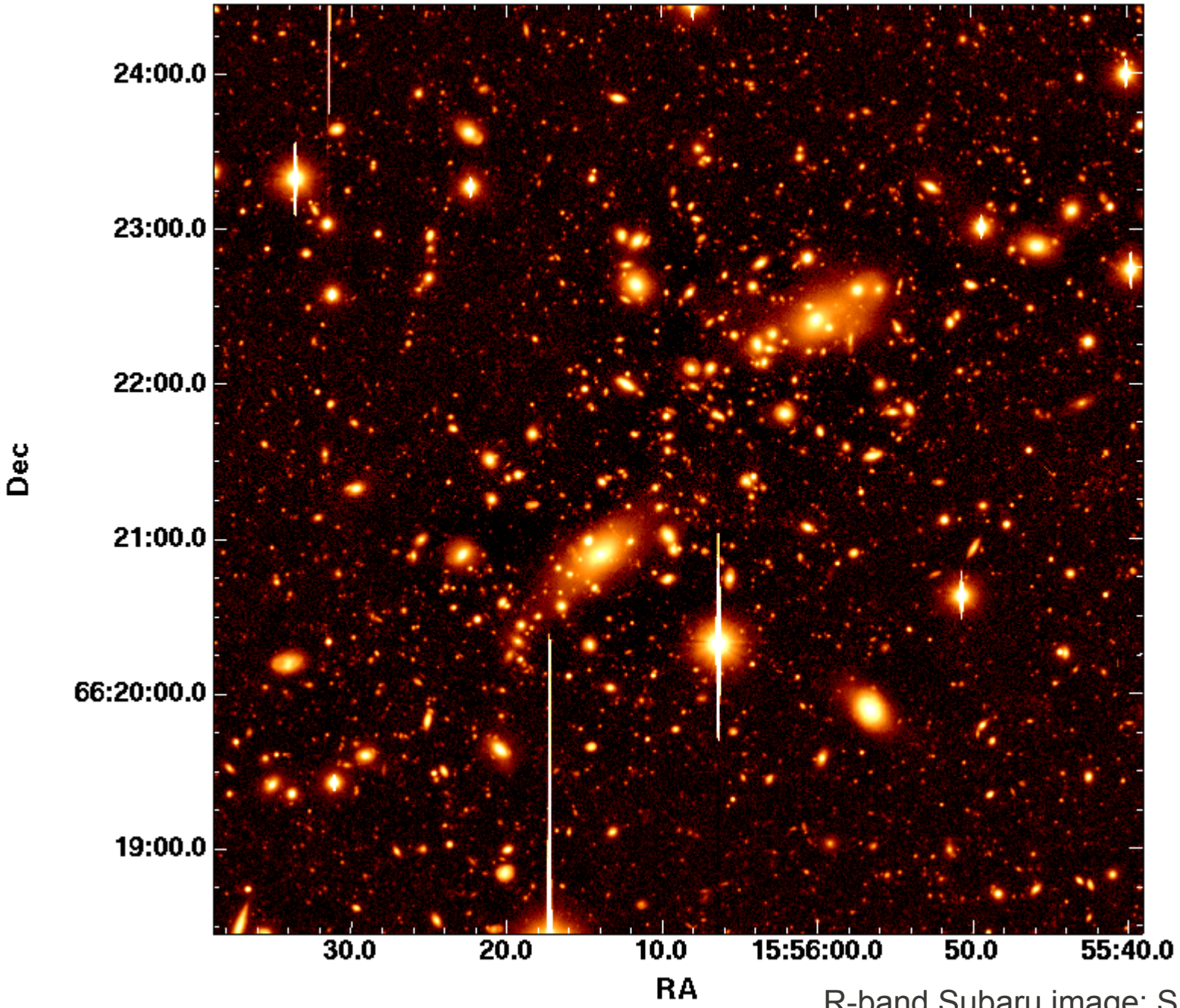


Brunetti et al. 2009

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

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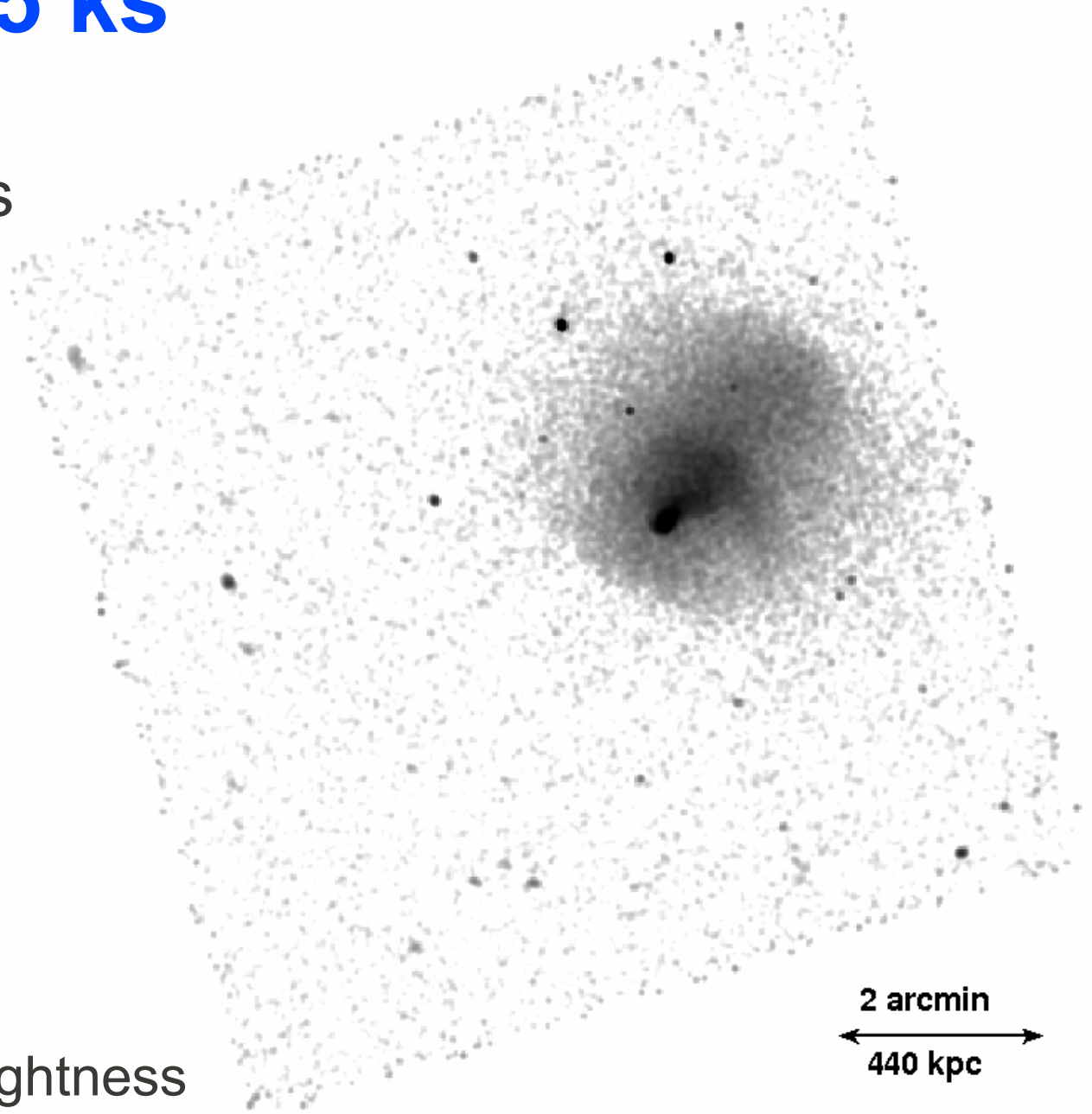
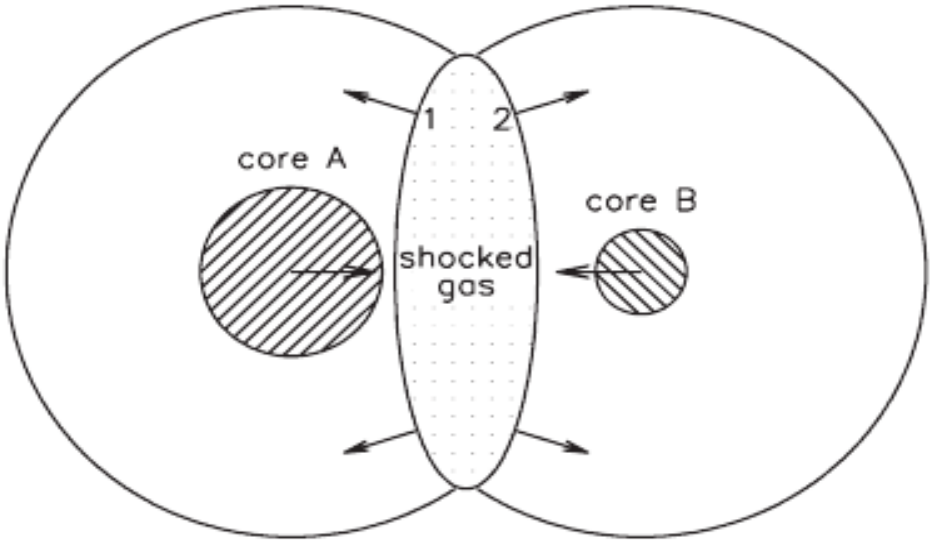
- $T_X = 6.7$ keV
- redshift 0.23

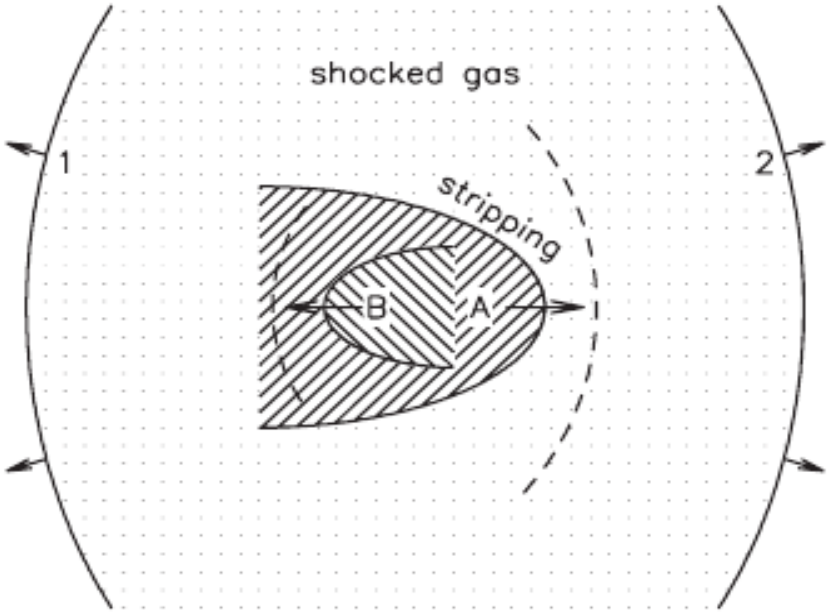


X-ray surface brightness

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:

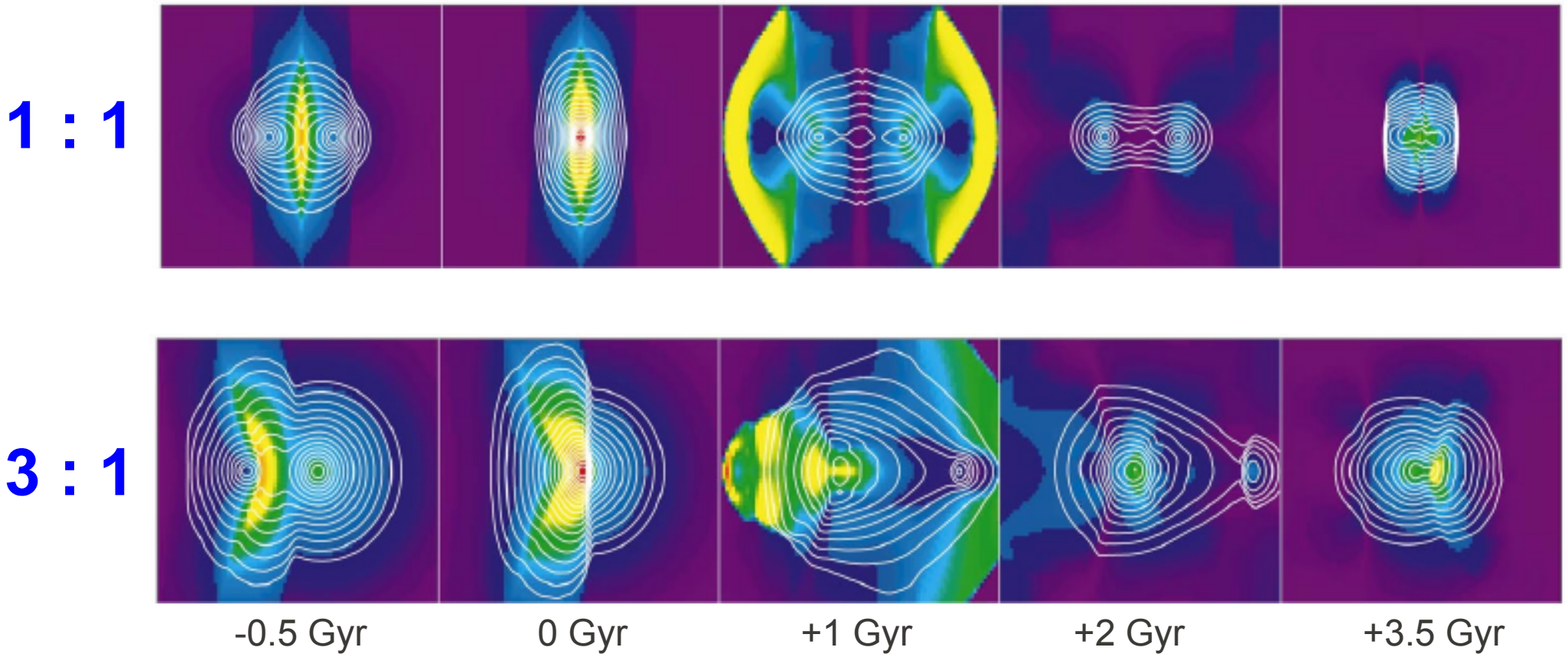
$$M = \left(\frac{2\,\rho_2/\rho_1}{\gamma + 1 - \rho_2/\rho_1 (\gamma - 1)} \right)^{1/2}$$

Also independently from the temperature jump.

Bullet cluster has shock Mach no. **M = 3.0 ± 0.4** (4700 km/s)

Upstream shock

- Mass ratio of A2146 merger is around **3:1**



Ricker + Sarazin 2001

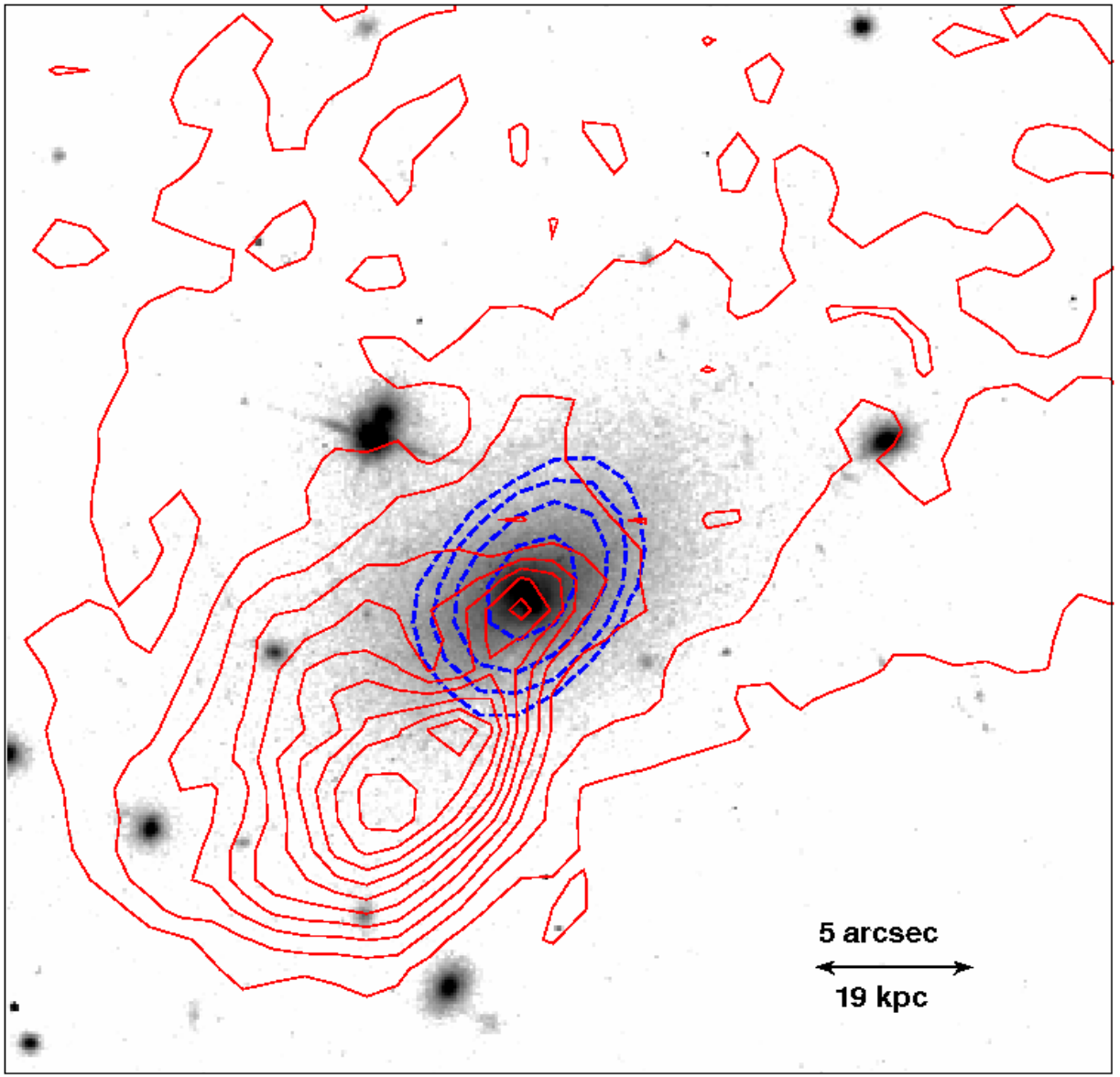
Location of BCG

- Brightest cluster galaxy located *behind* X-ray peak

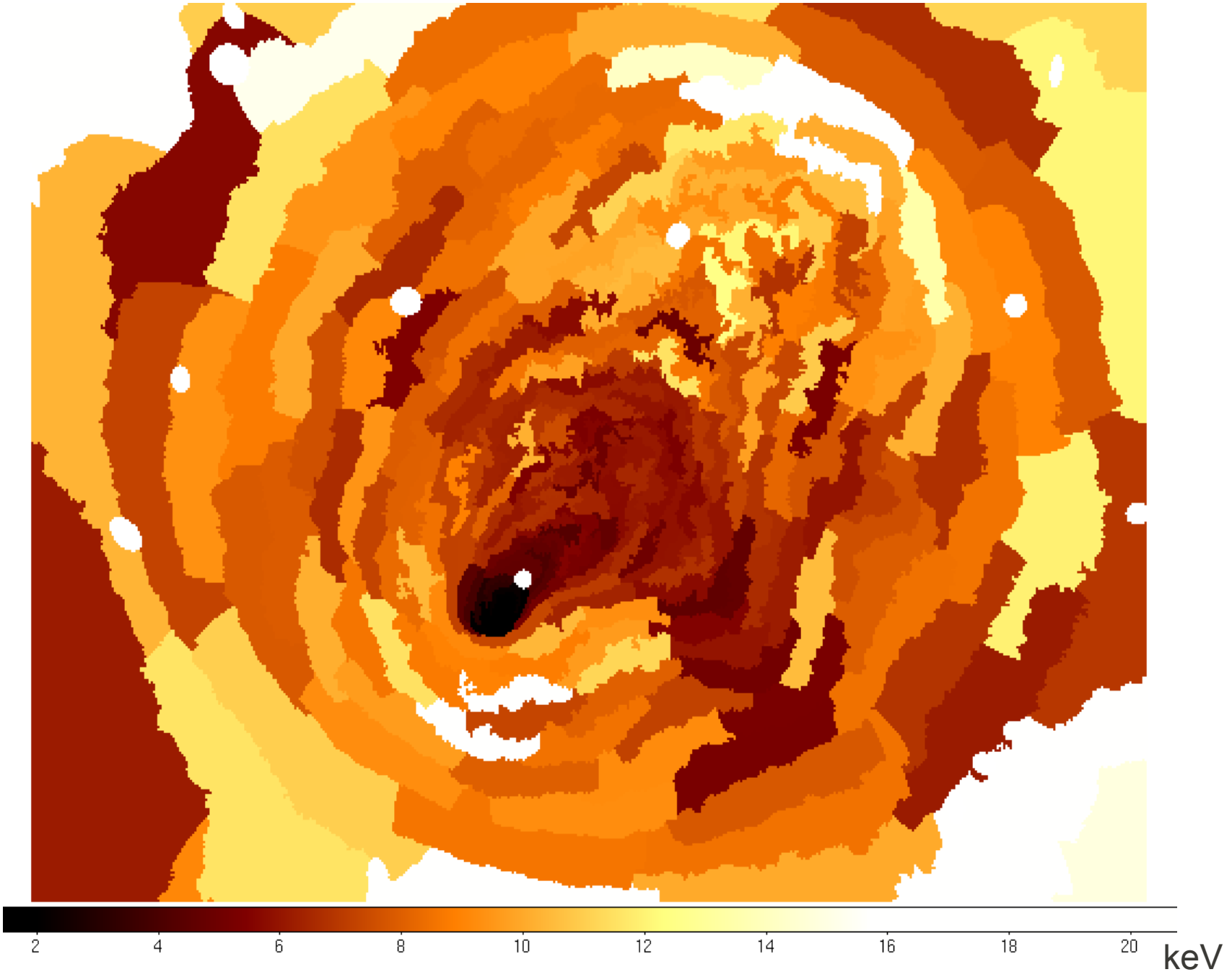
Optical

X-ray

Radio

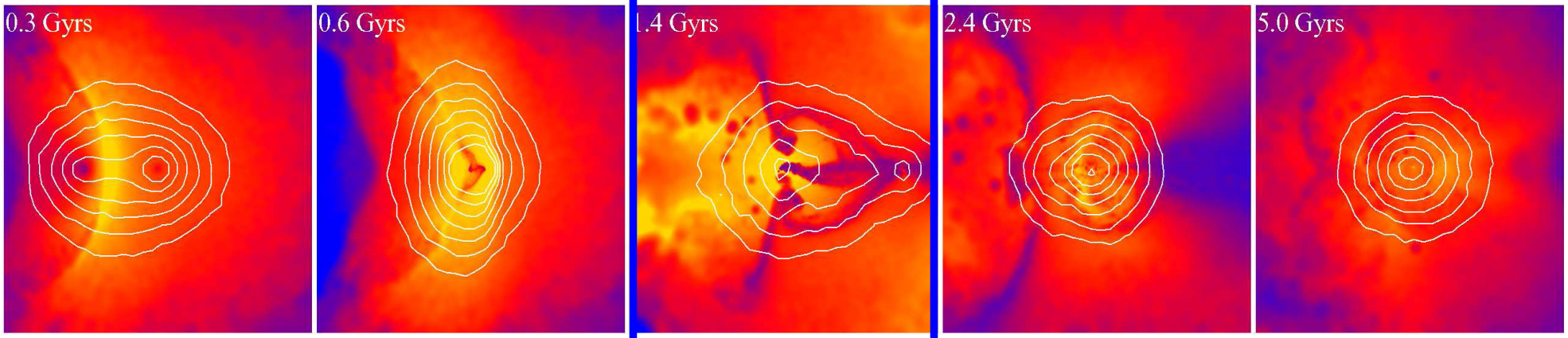


Temperature map

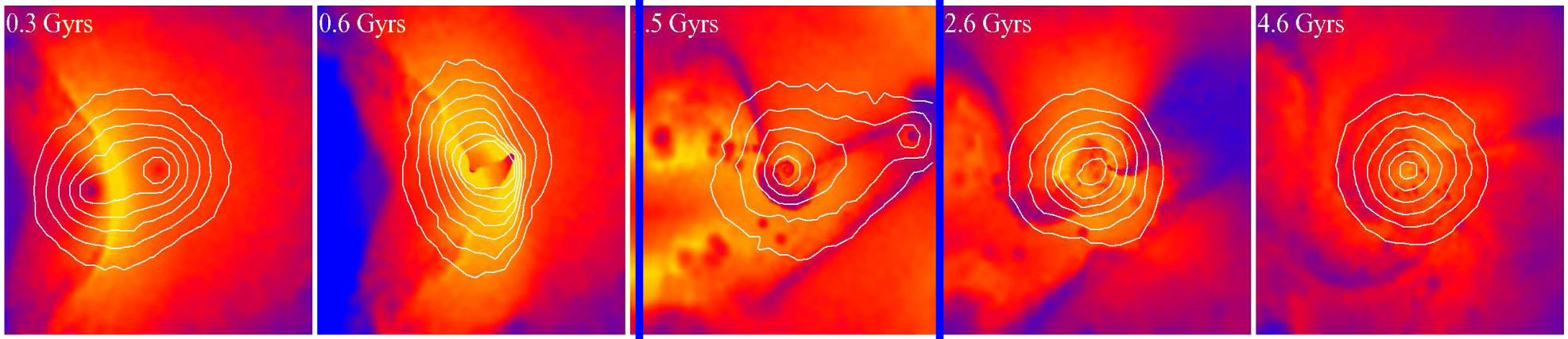


Plume structures

Zero impact parameter

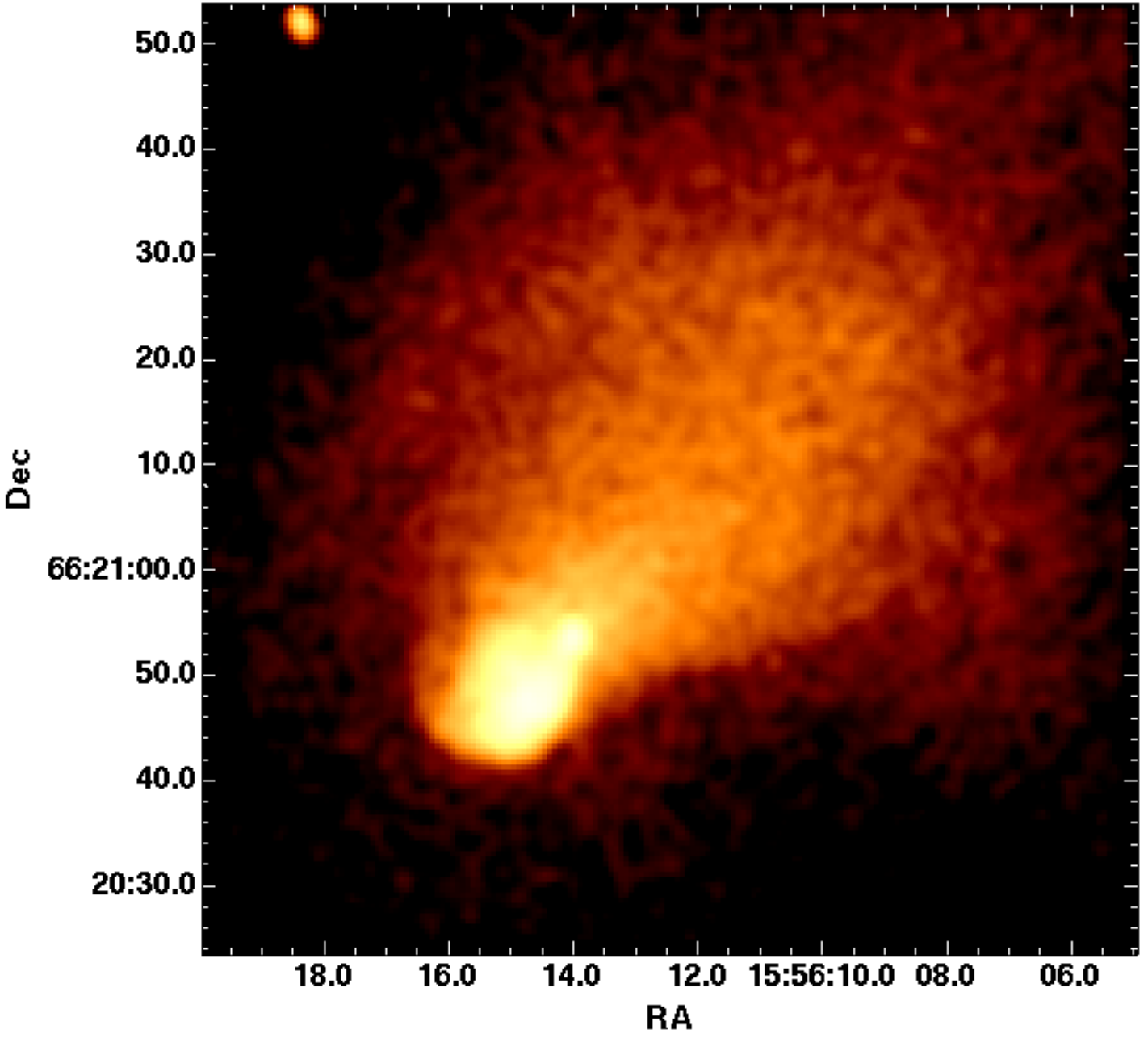


Non-zero impact parameter



Poole et al. 2006

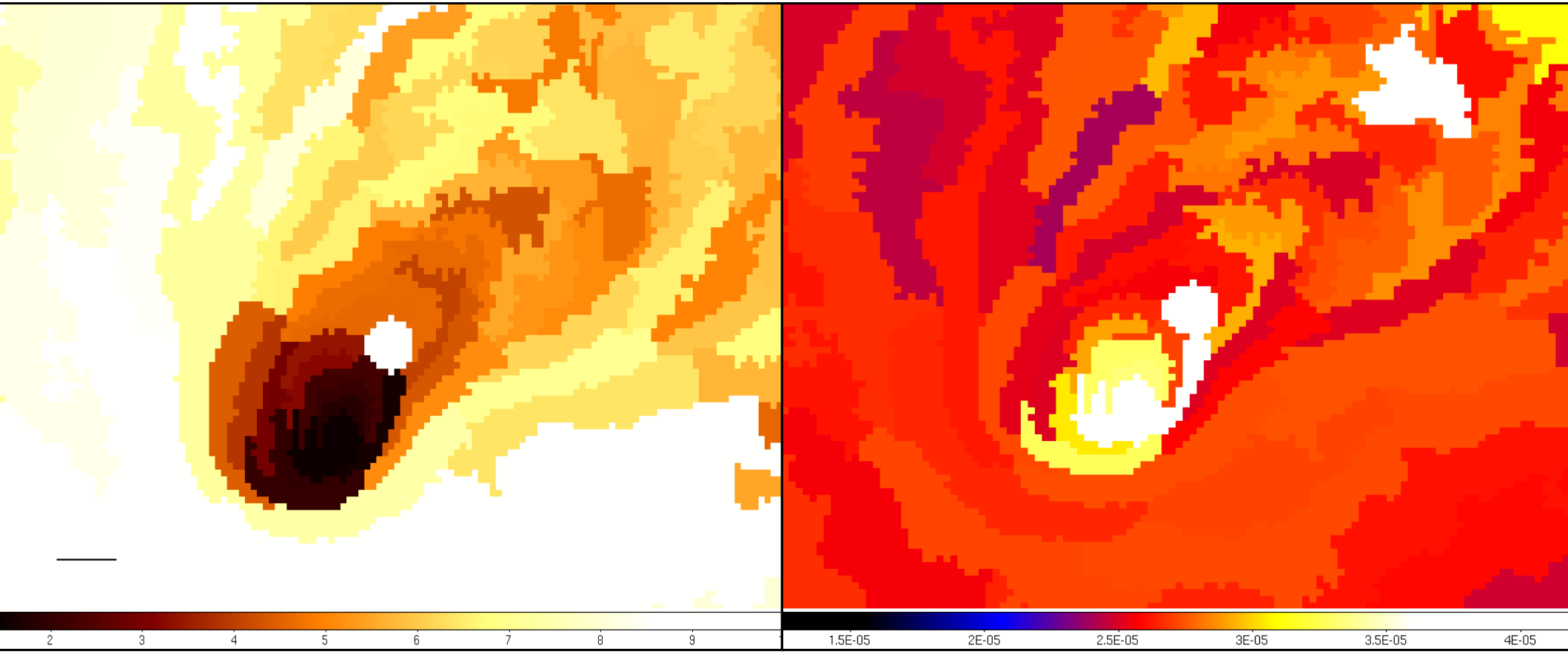
Core structures



Core structures

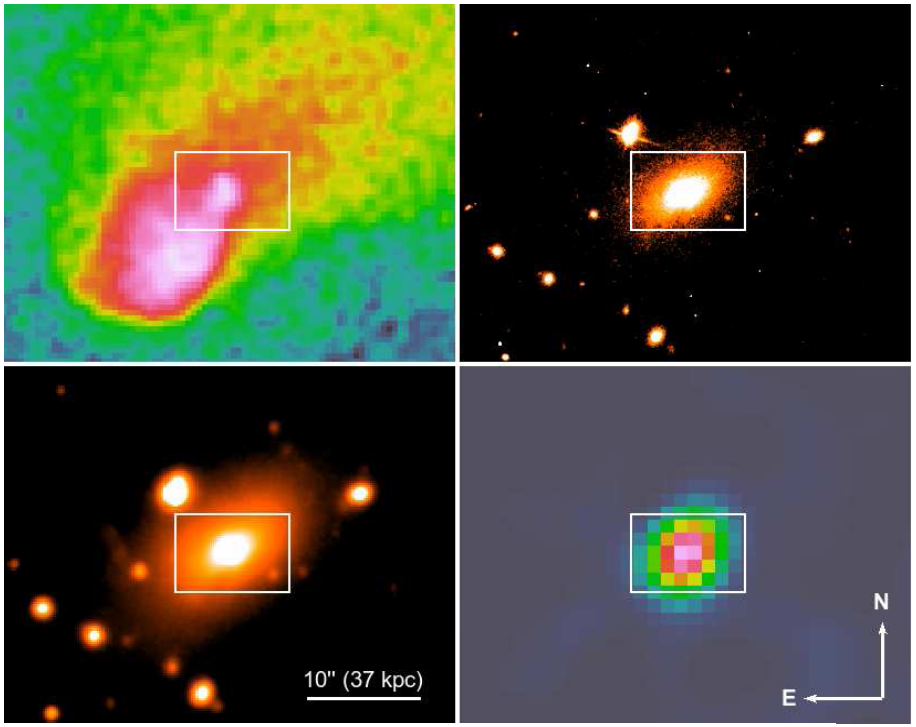
Temperature

Emission measure

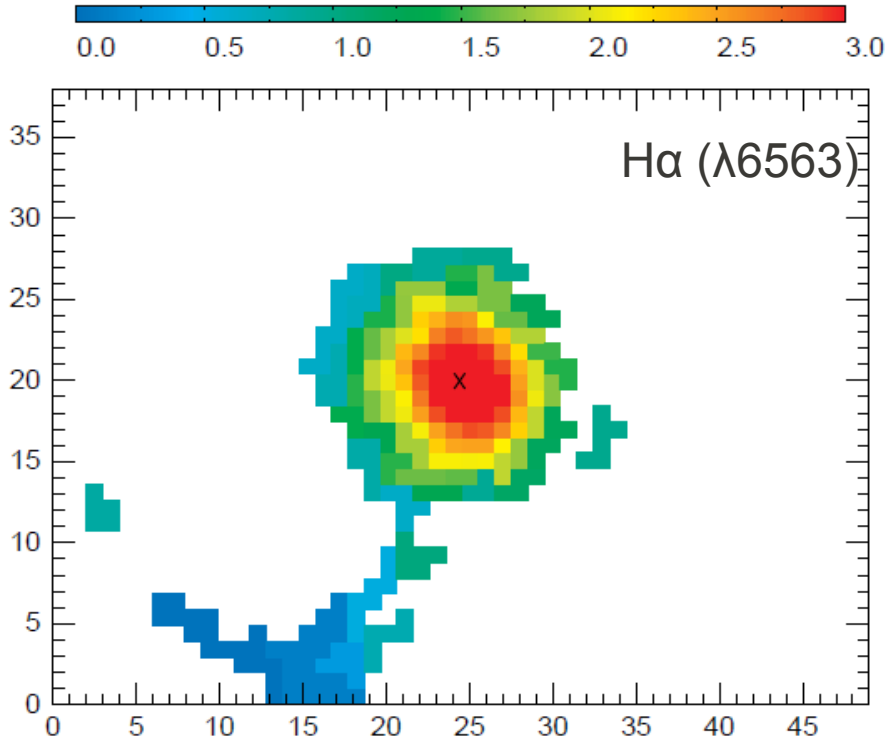


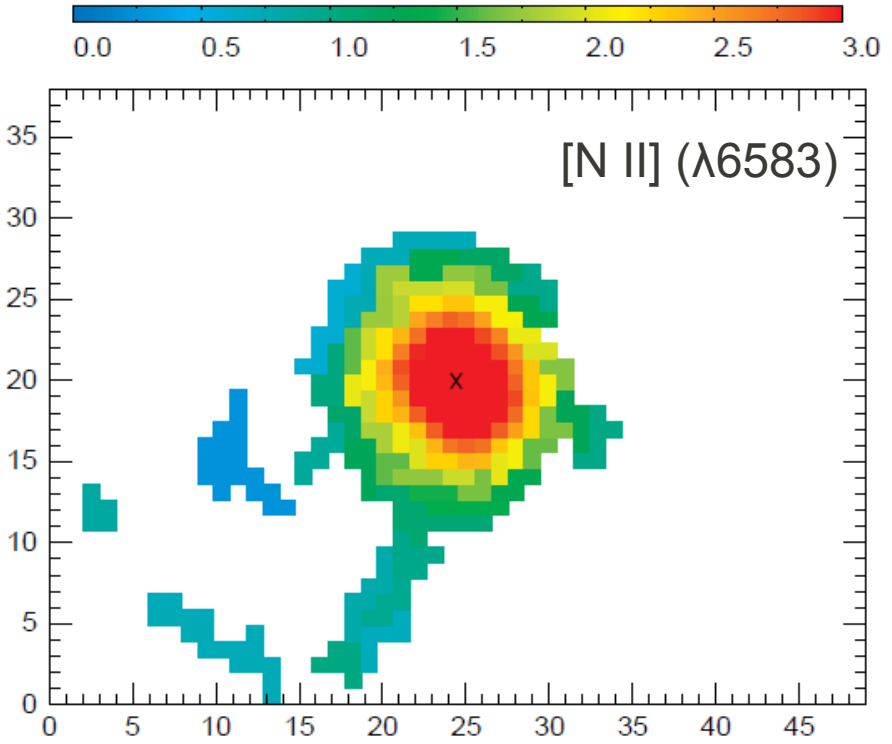
IFU observations

- WHT Oasis observations of optical emission lines in the BCG



FOV 10 x 7 arcsec (37 x 26 kpc)





Becky Canning

IFU observations

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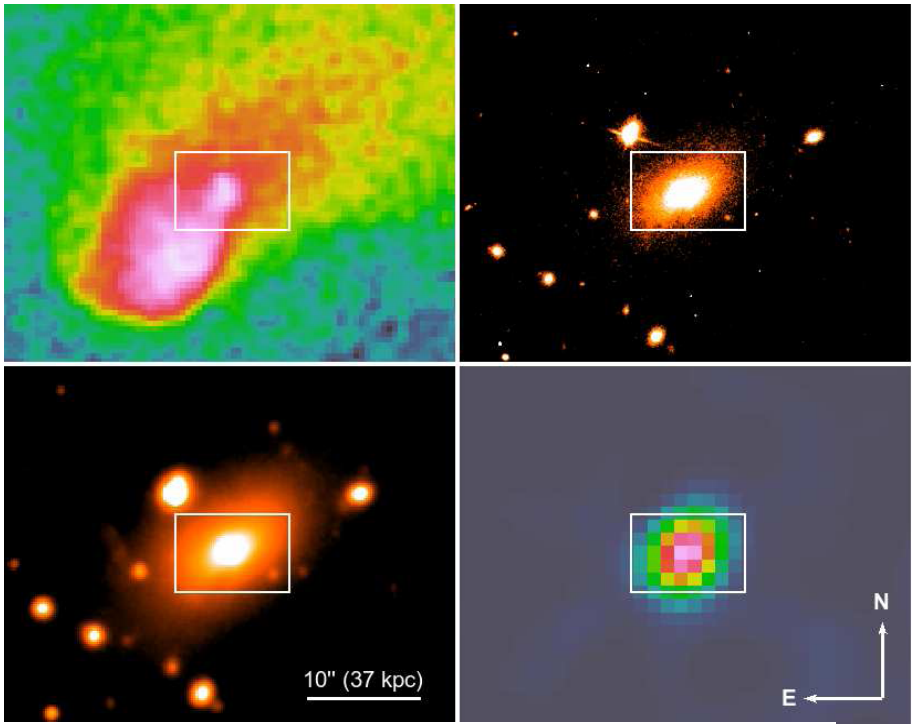

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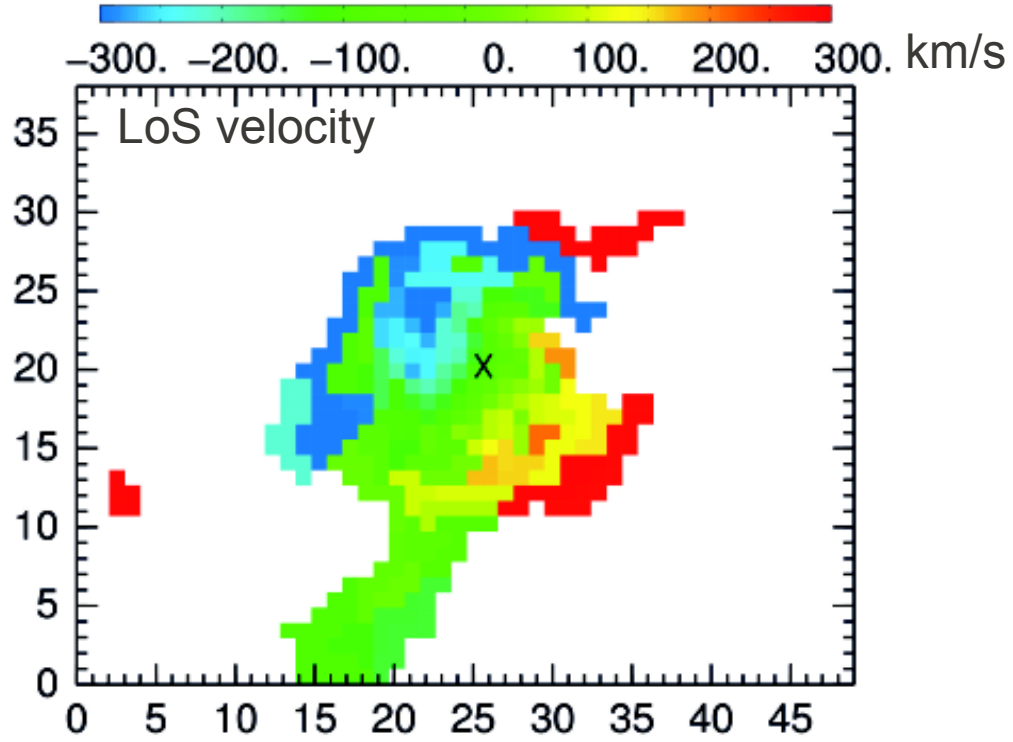

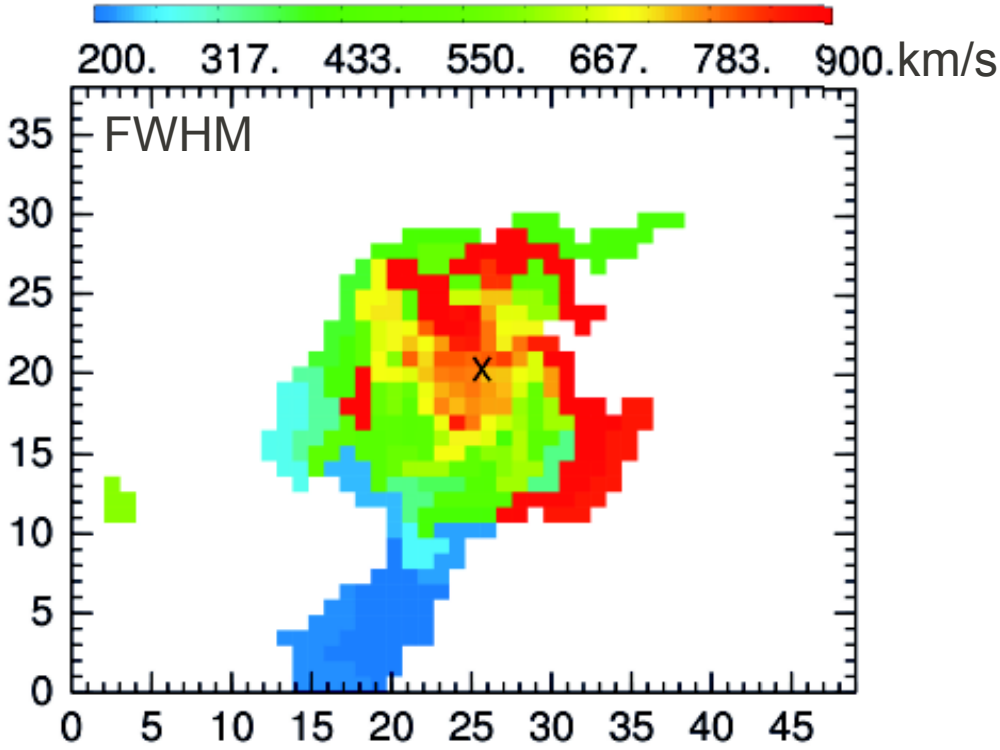

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