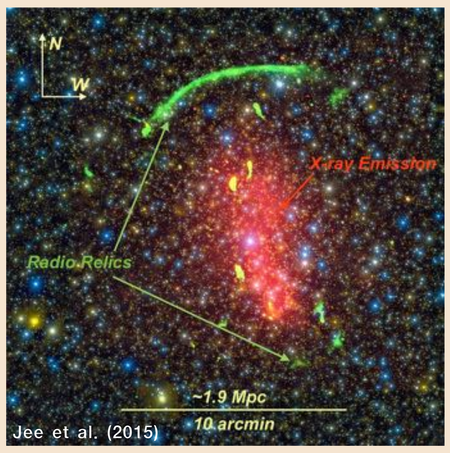
Discovery of a Radio Relic in the Massive Merging Cluster SPT-CL J2023-5535 from the ASKAP-EMU Pilot Survey

Authors

"HyeongHan Kim", M. James Jee, Lawrence Rudnick, David Parkinson, Kyle Finner, Mijin Yoon, Wonki Lee, Gianfranco Brunetti, Marcus Brüggen, Jordan D. Collier, Andrew M. Hopkins, Michał Michałowski, Ray P. Norris, Chris Riseley

README.md

- ASKAP consists of 36 antennae each 12m in diameter.
- ASKAP-EMU continuum survey aims to cover ~75% of the entire sky.
- Pilot survey data is publicly available.



- Cluster mergers exert vast amount of energies and generate a merger shock.
- It accelerates electrons via diffusive shock acceleration, and we often observe them as a radio relic.

ASKAP-EMU Pilot Survey

- Zheng et al. (in prep.) reported diffuse radio emission (radio halo; RH) in SPT-CL J2023-5535.
- With the advance of ASKAP-EMU pilot survey (Norris et al. in prep.), we confirmed the radio halo and discovered a radio relic (RR).
- The halo extends over ~1 Mpc with a spectral index of -1.04 ± 0.05.
- The relic has a size of ~0.5 Mpc with a flat spectral index of -0.76 ± 0.06.

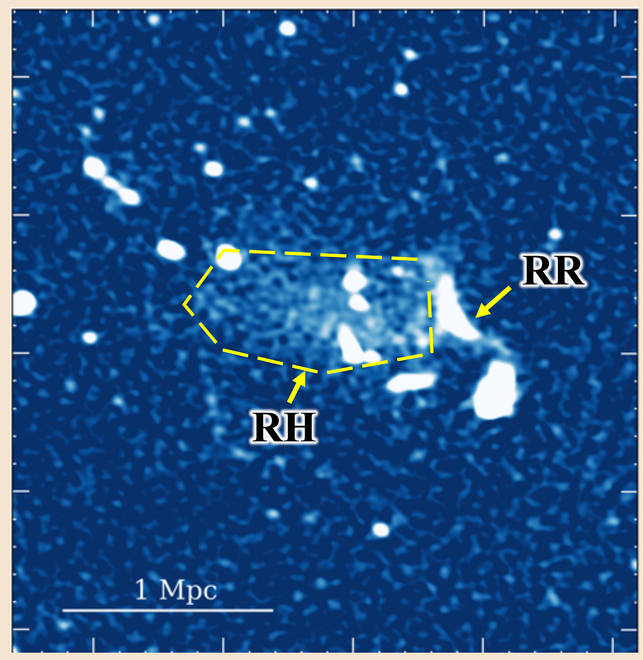
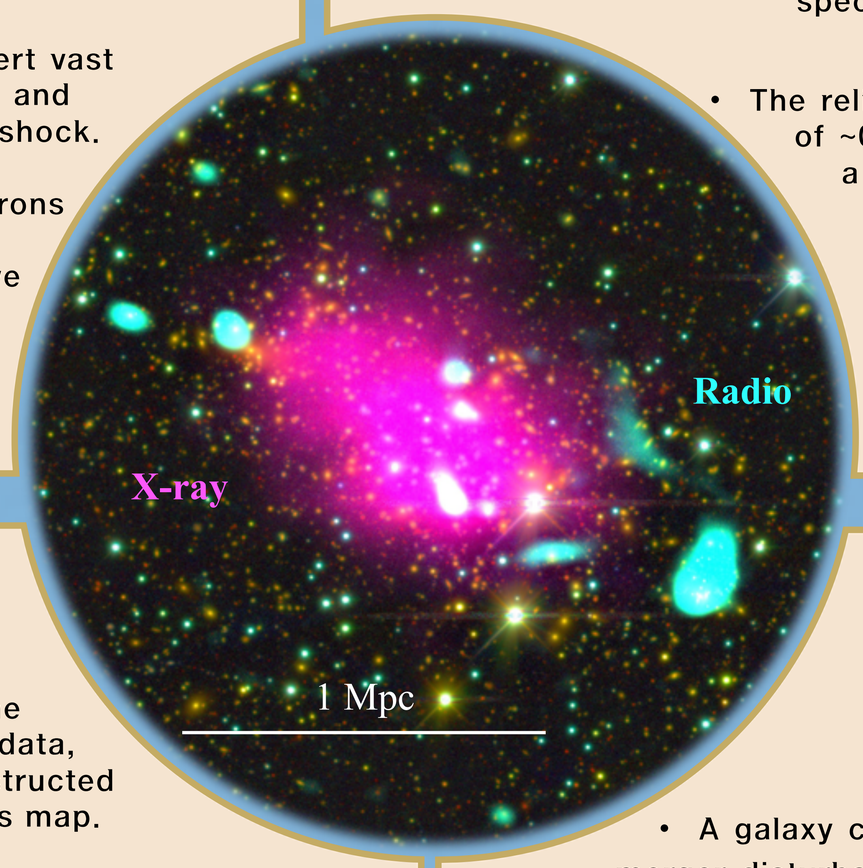


Figure 1. ASKAP-EMU pilot survey full resolution (12"×11") image of SPT-CL J2023-5535. The radio halo (RH) and radio relic (RH) are indicated by a yellow arrow, having a flux density of $S_{943\,\mathrm{MHz}} = 31.3 \pm 0.6$ and 16.2 ± 0.2 mJy, respectively. The relic is linked to the nearby radio galaxy with a high significance ($> 3\sigma$).



DECam: Weak-lensing analysis

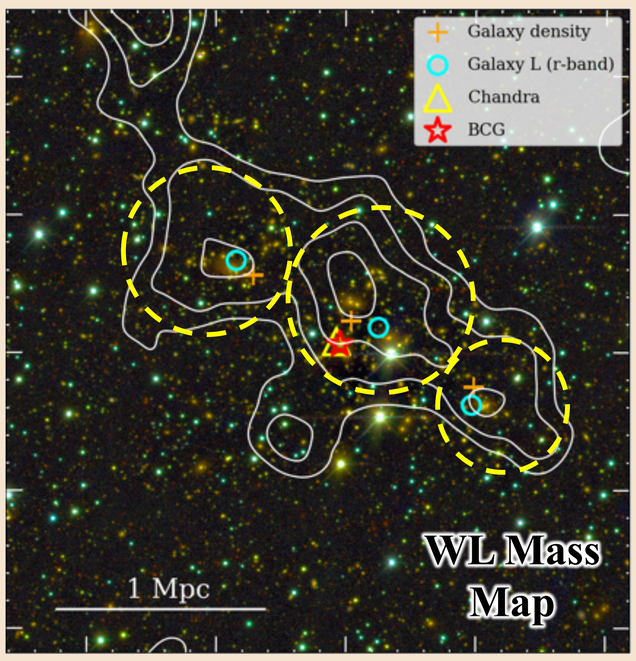


Figure 2. Optical color-composite image with the overlays of the weak-lensing mass contours (white). The mass distribution is composed of three sub-clusters indicated by yellow circles roughly representing the masses. The mass peaks are consistent with the galaxy density/luminosity peaks. The X-ray peak coincides with the spectroscopically confirmed BCG.

- Using the DECam data, we constructed WL mass map.
- The cluster is comprised of three subclusters with a significance higher than 3σ.
- Each peak coincides with the galaxy density/luminosity peaks.
- The estimated masses are within a range of $\sim 1-3\times10^{14}\,M_{\odot}$, and the mass of the total system is $1.04 \pm 0.36\times10^{15}\,\mathrm{M}_{\odot}$.
- Given the position of the relic and sub-clusters, the central and eastern subclusters have gone through a ~1:1 major merger that generated the radio relic.

Chandra

- A galaxy cluster merger merger disturbs the ICM and makes the X-ray distribution elongated.
- Using the ~20 ks *Chandra* X-ray image, we detected a surface brightness drop ($C = 1.8 \pm 0.5$) at the location of the relic.
- Despite of the poor photon statistics ($\sim 2\sigma$), we found a hint of temperature jump ($\mathrm{T_{pre}} = 7.3 \pm 3.3$ and $\mathrm{T_{post}} = 20 \pm 12$ keV).
- They hint the presence of an X-ray shock with a low Mach number.

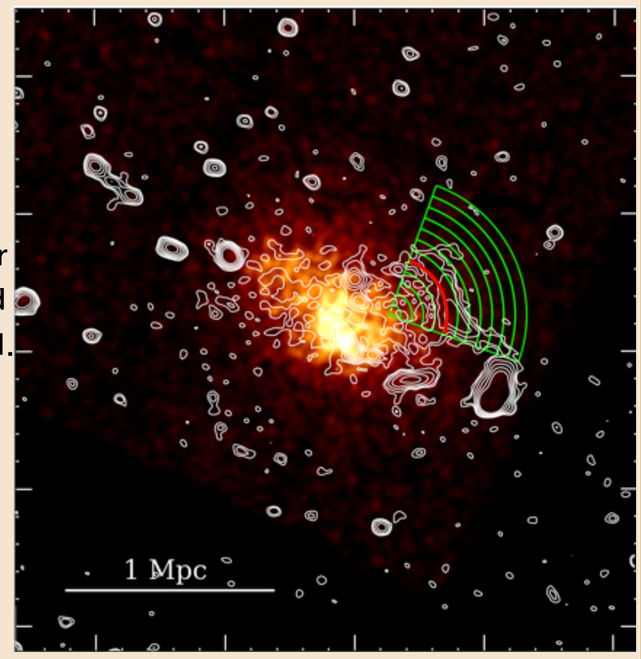


Figure 3. Exposure-corrected, point source removed *Chandra* X-ray surface brightness map with the ASKAP-EMU pilot survey contours. (white). Green fan-shaped region shows where the surface brightness profile is extracted. The red arc indicates where the relic is located, and the X-ray surface brightness drop is located near that position as well. Elongated X-ray distribution tells us how the cluster merger happened in the past.

Time-since-collision

- Dynamical timing argument (Sarazin 2002)

- ➢ Current separation is 0.5 Mpc, and we assume that the relative velocity remains constant.
- ➢ Time-since-collision (TSC) will be $\frac{0.5\ [\mathrm{Mpc}]}{1800\ [\mathrm{km/s}]} \approx 0.3$ Gyr

- Density compression from the X-ray SB drop
  - ➢ $\mathcal{M} = 1.6 \pm 0.5$
  - ➢ TSC ~ 0.3 Gyr
- Temperature jump from the X-ray
  - ➢ $\mathcal{M} = 2.5 \pm 1.3$
  - ➢ TSC ~ 0.2 Gyr
- Diffusive shock acceleration model
  - ➢ $\mathcal{M} \gtrsim 2.9$
  - ➢ TSC $\lesssim$ 0.2 Gyr

Merger happened in the recent past.

Prerequisites

1. Shock speed
   $v = \mathcal{M} \cdot c_s$
2. Sound speed at the cluster periphery
   $T_{gas} \sim 7$ keV
   $c_s \sim 1300\ km/s$
3. Shock propagation distance
   $D \sim 0.5$ Mpc

Flat spectral index

- The spectral index of the relic is flat $\alpha_{int} = -0.76 \pm 0.06$
- Test-particle DSA theory predicts $\alpha_{inj} = \alpha_{int} + 0.5 \rightarrow \alpha_{inj} = -0.26 > -0.5$
  (Brüggen et al. 2012; Brunetti & Jones 2014; Kang 2015)
- What causes the flat spectral index?
  - ➢ It could be due to the re-acceleration of fossil electrons.
  - ➢ The local AGN can provide the pre-accelerated electrons.

Figure 4. Close-up view of the radio relic and western radio galaxy that are connected each other. Optical counterpart is indicated by a yellow arrow. Green polygon shows the area we chose to define the relic and is used for the flux measurement. White contours denote the $3\sigma_{rms}\times3^n$ levels of the full-resolution image where n=0, 1, ···, 5, 6.

Conclusion

- ✓ We discovered a radio relic in SPT-CL 2023-5535 from the ASKAP-EMU pilot survey.
- ✓ With weak-lensing analysis, we identified three subclusters and constructed a merger scenario.
- ✓ The merger shock may have re-accelerated fossil electrons from the local AGN.
- ✓ *Chandra* 133 ks & ATCA 10 hours of observations are planned.
- ✓ We will confirm the flat spectral index and the presence/properties of the X-ray shock.

References

- Brüggen et al. 2012, SSRv, 166, 187
- Brunetti & Jones 2014, IJMPD, 23, 1430007-98
- Kang 2015, JKAS, 48, 155
- Sarazin 2002, ASSL, 272, 1
- Norris et al. in prep.
- Zheng et al. in prep.

Link to paper

For more details, go to HyeongHan+20!