# Explaining the Formidable Stellar Formation Rate of a Massive Galaxy Cluster at z∼ 1.7

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## A Confounding History

*SpARCS1049+56* is a massive galaxy cluster residing at a redshift equal to 1.7; while there are several fascinating features in this cluster, perhaps the most captivating is its extremely elevated stellar formation rate $\sim 860 M_{\odot}/yr$ which is offset considerably from the BCG.

### UV/NIR[1][2]:

- AGN-removed stellar formation rate (SFR) at $856 \pm 128 M_{\odot}$
- Extended and Luminous Tidal Tail ($L_{IR} = 6.2 \times 10^{12}\ L_{\odot}$)
- massive molecular gas reservoir ($\sim 10^{11} M_{\odot}$)

### Radio[3]:

- Highly compact, surrounds the BCG, and relatively weak ($4.4 \pm 3.5 \times 10^{33}$W)

## How do we explain this SFR?

- **Major Merger**: The Brightest Cluster Galaxy (BCG) at the heart of *Sp1049* undergoing a merger with a BCG of a neighboring cluster
- **Several Minor Mergers**: *Sp1049*'s BCG is in the act of cannibalizing smaller satellite galaxies in the cluster
- **Cooling Flow**: extremely hot ($\sim 10^8$K) intra-cluster medium, comprised of gas and dust residing at the heart of the cluster's Dark Matter Halo, succumbs to its own gravitational potential and triggers a mass cooling-flow

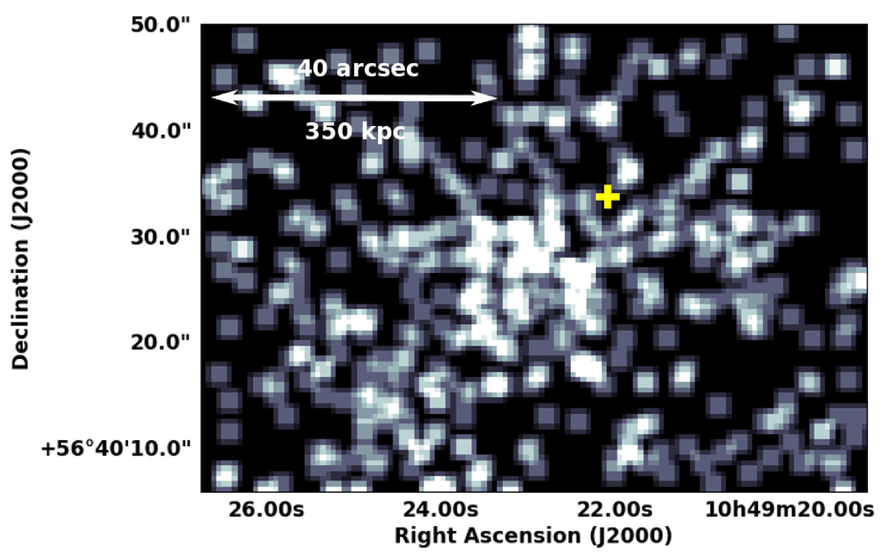


Figure 1: Central image of *Sp1049+56* in the broad band ($0.5 - 7.0$keV). The unbinned image has been smoothed with a Gaussian of $\sigma = 3$. The yellow cross denotes the location of the BCG: *10:49:22.6 +56:40:32.6*.

## Multi Wavelength Imaging

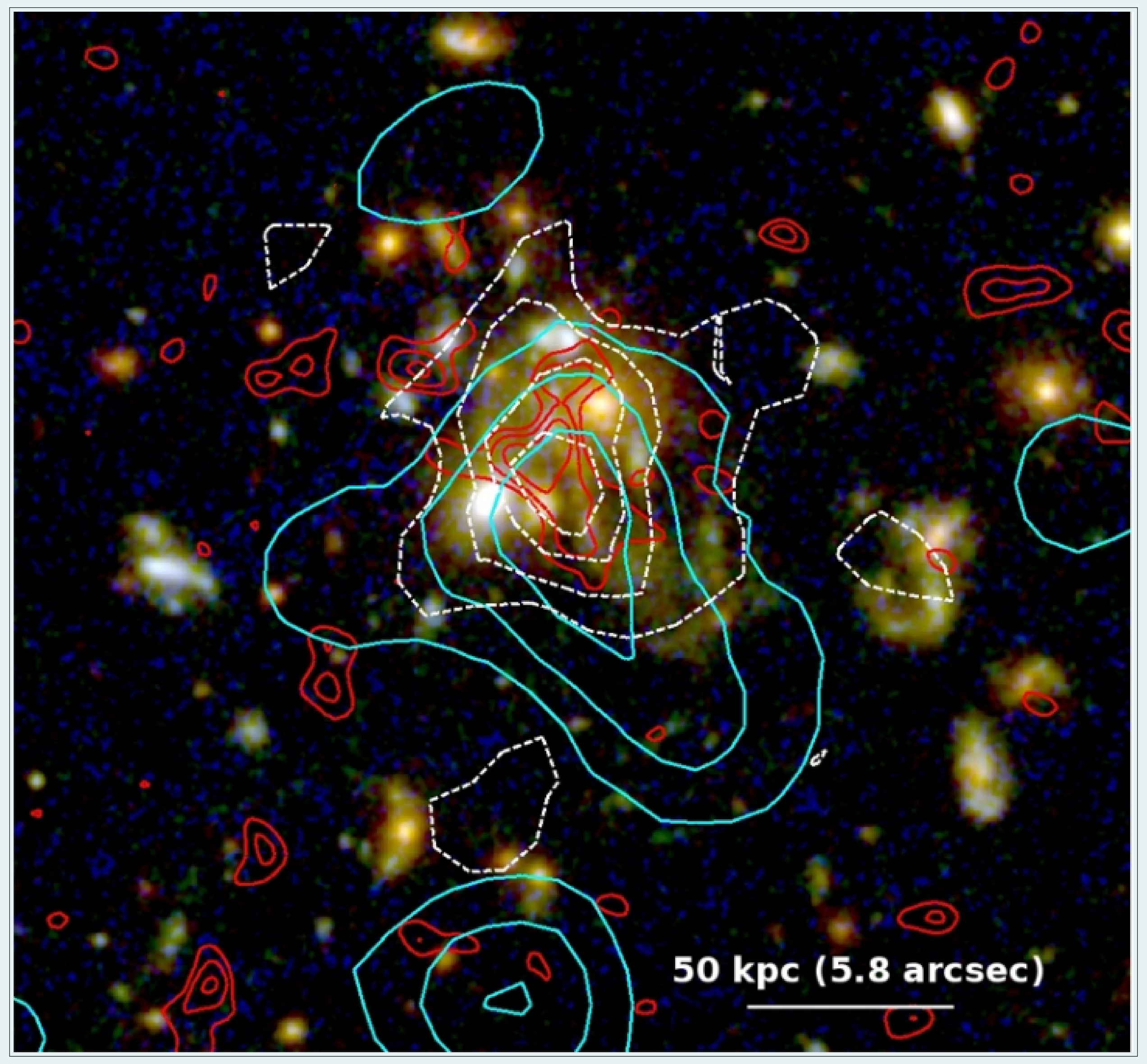


Figure 2: Central image of SpARCS 1049+56 using the HST F105W and F160W filters as the background image. The cyan contours correspond to $4\sigma$ X-ray emission between 0.7 and 1 keV, while the white and red contours represent the Spitzer MIPS 24 micron and VLA CO (1-0) emission, respectively. This image clearly demonstrates that the ICM is cospatial with the region of star formation. Therefore, the star burst appears to be diven by an ICM cooling flow.

## X-ray Analysis

The data was spectroscopically fit using `Xspec v12.10.1`, `Sherpa v1`, and `python v3.5`. An abundance ratio of 0.3 was assumed for all fits. The background region was chosen to be off chip at an offset of a considerable distance ($\approx 1Mpc$) and was kept consistent for all exposures. We fit each observation's source and background regions simultaneously using `Xspec`'s native implementation of the `c-statstic`. The background models both replicate the Cosmic X-ray Background (CXB) [4] [5]. Both models were tested for all spectroscopic results; we found no significance in results regardless of the background model employed. Furthermore, we tested two absorbed thermal emission models: `apec` and `mekal`. The final fits were calculated using the McDonald background model and an absorbed `apec` model. The fits yield a temperature of kT=5.71 ± 1.57keV and a soft-band ($0.5 - 2.0$keV) unabsorbed X-ray luminosity of L=$4.29^{\pm 0.19} e^{44}$ergs/s. These values are consistent with a massive galaxy cluster harboring a cooling core.

## A Cooling Flow?

Due to the minimal counts ($\sim 250$), the coefficient of surface brightness, $c_{sb}$, acts as the strongest indication of a cooling flow in *Sp1049*. The $c_{sb}$ is the ratio of soft-band fluxes for the inner and outer regions:

$$c_{sb} = \frac{F(R < 40kpc)}{F(R < 400kpc)} \quad (1)$$

We are interested in the following regimes:

$$\begin{cases} \texttt{Non Cool Core} & c_{sb} < 0.075 \\ \texttt{Moderate Cool Core} & 0.075 < c_{sb} < 0.155 \\ \texttt{Strong Cool Core} & c_{sb} > 0.155 \end{cases}$$

Having calculated the $c_{sb}$ after prudent data reduction, we discover that the cluster lies well within the range of a cool core cluster.

| Indicator | Value | Lower | Upper |
|---|---|---|---|
| Net Count Rate | 0.093 | 0.048 | 0.172 |
| Net Energy Flux | 0.184 | 0.095 | 0.340 |

Table 1: Coefficient of Surface Brightness calculations using two key indicators.

## Cosmological Context

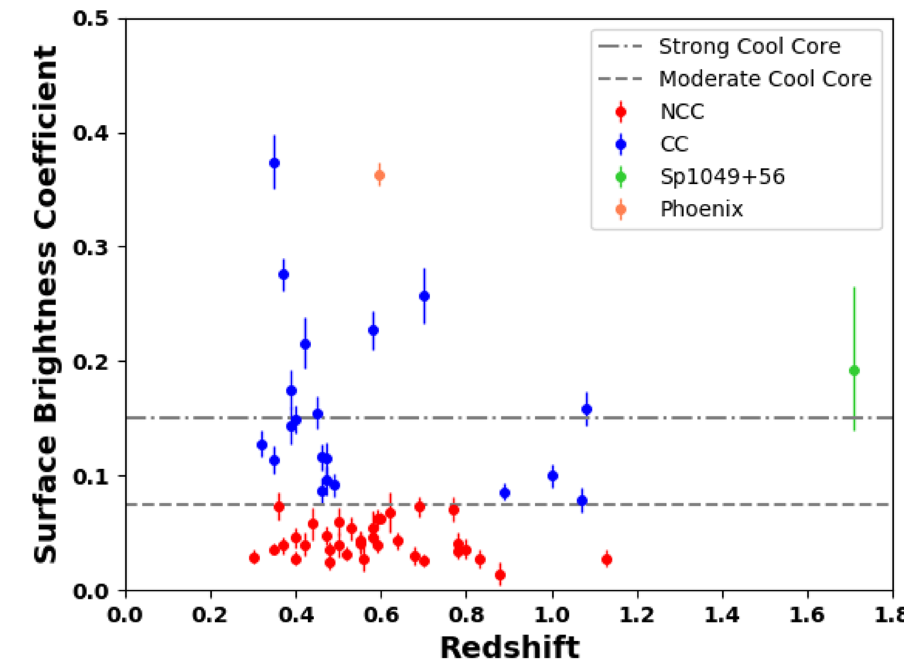


Figure 3: Surface brightness coefficient of SpARCS 1049 compared to South Pole Telescope Clusters taken from McDonald et al. 2013[5]

- **X-ray Provenance**: While the field is clearly muddled with several intervening structures, we have several indicators that the emission is likely coming from $z = 1.7$
- **Cool-Core**: Based off X-ray data, *Sp1049* likely harbors a significant offset cooling flow which can explain the elevated stellar formation rate
- **Intra Cluster Light**: *Sp1049* demonstrates the creation of the ICL taking place *in-situ* due a cooling flow
- **Feedback**: Clear indication of a lack of suppression by the central SMBH on the stellar formation

## References

[1] Webb, T. et al. 2015 ApJ
[2] Webb, T. et al. 2017 ApJ
[3] Trudeau, A. et al. 2019 ApJ
[4] Sun, M. et al. 2009 ApJ
[5] McDonald, M. et al. 2013 ApJ
[6] Zou, S. et al. 2016 MNRAS

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