Investigating the formation of a galaxy with a trail of star clusters

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Overview

The MACS 0417 galaxy cluster at a redshift of z = 0.443 is one of the most massive clusters known based on weak lensing X-ray, and Sunyaev–Zel'dovich analyses [1]. In this study, we explore a hypothesis involving galactic interactions within MACS0417. Our investigation centers around the idea that two galaxies within this cluster may have passed through each other, resulting in a trail of dust being stripped from one of them. We examine the possibility that this cosmic event triggered star formation within the trail of dust, shedding light on the dynamic processes at play in this galactic environment. The key step in this study is to find the redshift as it acts as a cosmic ruler, enabling us to gauge the relative distances between the objects and to check if they're on the same plane or not.

1. Galaxy Overview

The data employed for generating the image and conducting photometric analysis originates from a diverse set of cutting-edge instruments, including the James Webb Space Telescope's Near Infrared Camera (NIRCAM) and Near Infrared Imager and Slitless Spectrograph (NIRISS) filters, as well as the Hubble Space Telescope's Advanced Camera for Surveys (ACS) filters. This multi-instrument approach allows us to capture a comprehensive view of the celestial scene, spanning a broad range of wavelengths. The remarkable capabilities of these space-based observatories enable us to obtain high-quality data that empowers our exploration of the intricate details, spectral characteristics, and spatial distribution of the astronomical objects within the observed field, facilitating a deeper understanding of the cosmic phenomena under investigation.

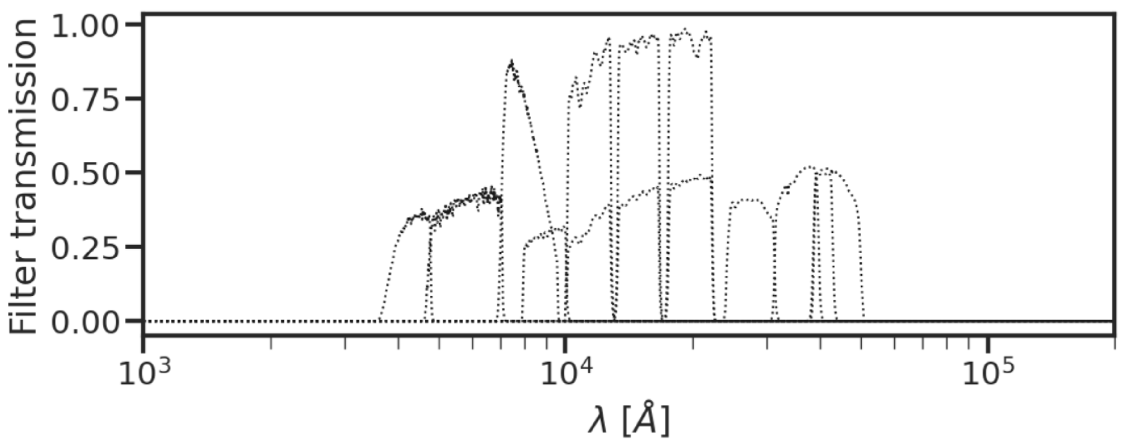

Fig. 1: Filter Throughput for each filter used in this project. The filters (starting from the left) are f435w, f606w, f814w, f090w, f115w, f115wn, f150w, f150wn, f200w, f200wn, f277w, f356w, f410m, f444w. The filters f435w, f606w and f814w represent the HST ACS filters. The filters ending with 'wn' represent the NIRCam filters and the rest are NIRISS filters. .

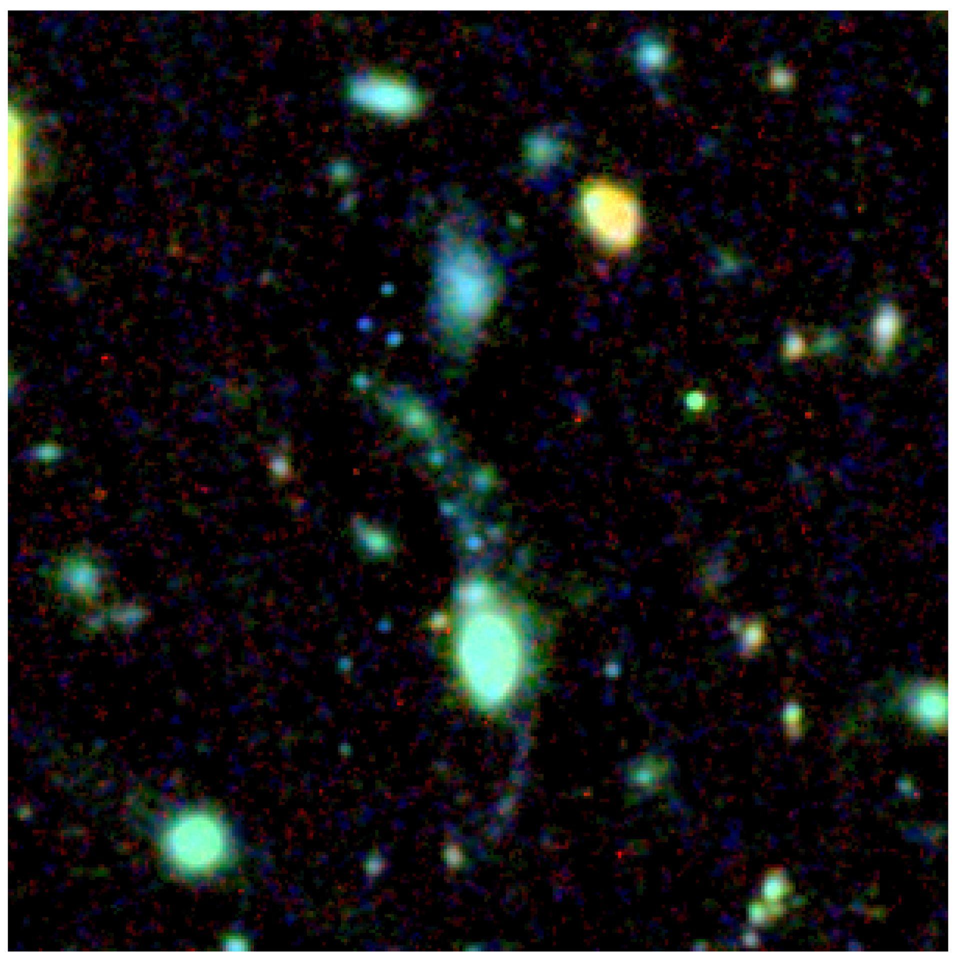

Fig. 2: The galaxy within MACS0417 is the focus of the study. It leaves a remarkable trail of dust in which it can be seen that star clusters have formed.

2. Segmentation Map

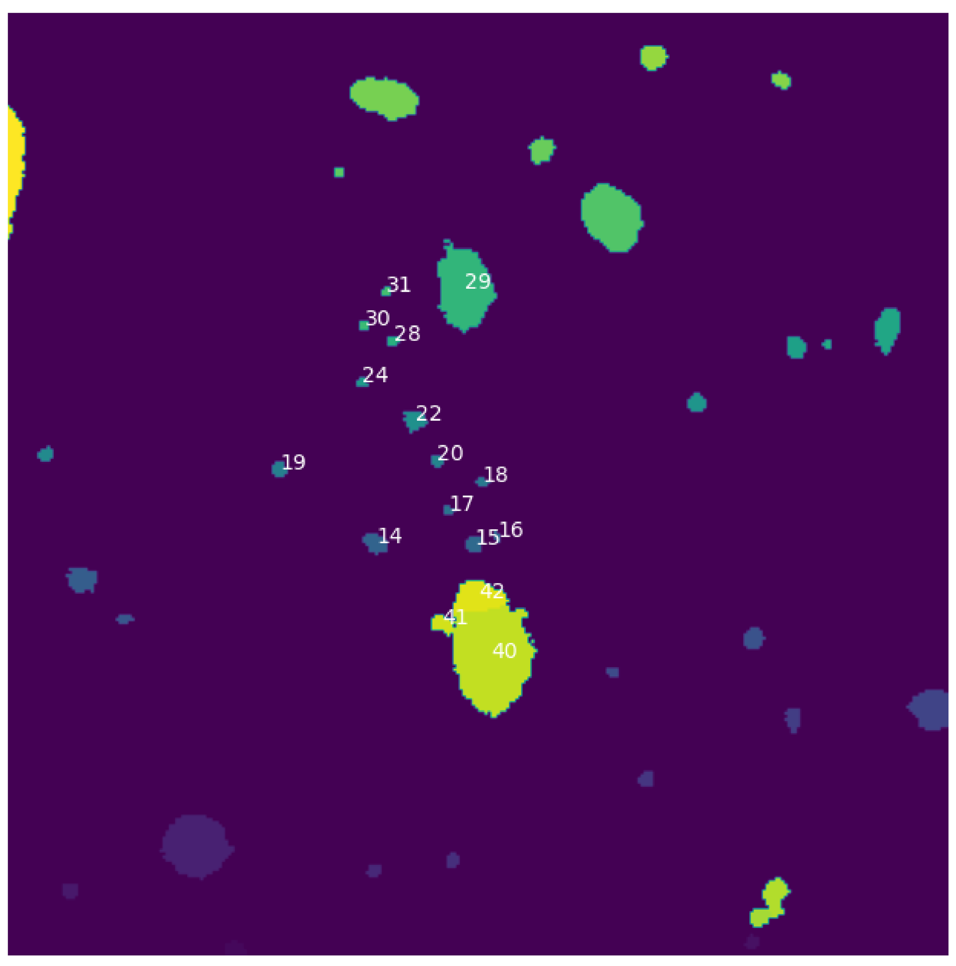

Fig. 3: A segmentation map highlighting the distribution of objects within the MACS0417 galaxy cluster. The numbers in the figure represent labels for each of the galaxies/star clusters. This map provides information about the location/size of the objects which can be used to perform aperture photometry.

3. Photometric Plots

The photometric plots were obtained by performing aperture photometry on the objects using Photutils library. To test the accuracy of the aperture photometry method, a gaussian source was inserted to the image before performing photometry (This object can be seen in the bottom left of the segmentation map). The resulting flux of the source was over 99% accurate which is a cause of confidence in the photometry method. However, the accuracy of the flux of the source dropped as the source looked more elliptical. To take that into account in the photometry of the galaxy/star clusters, a ratio of the semimajor axis to the semiminor axis was calculated for each object. If the ratio is close to one, then a circular aperture was used for the photometry, otherwise, an elliptical aperture was used.

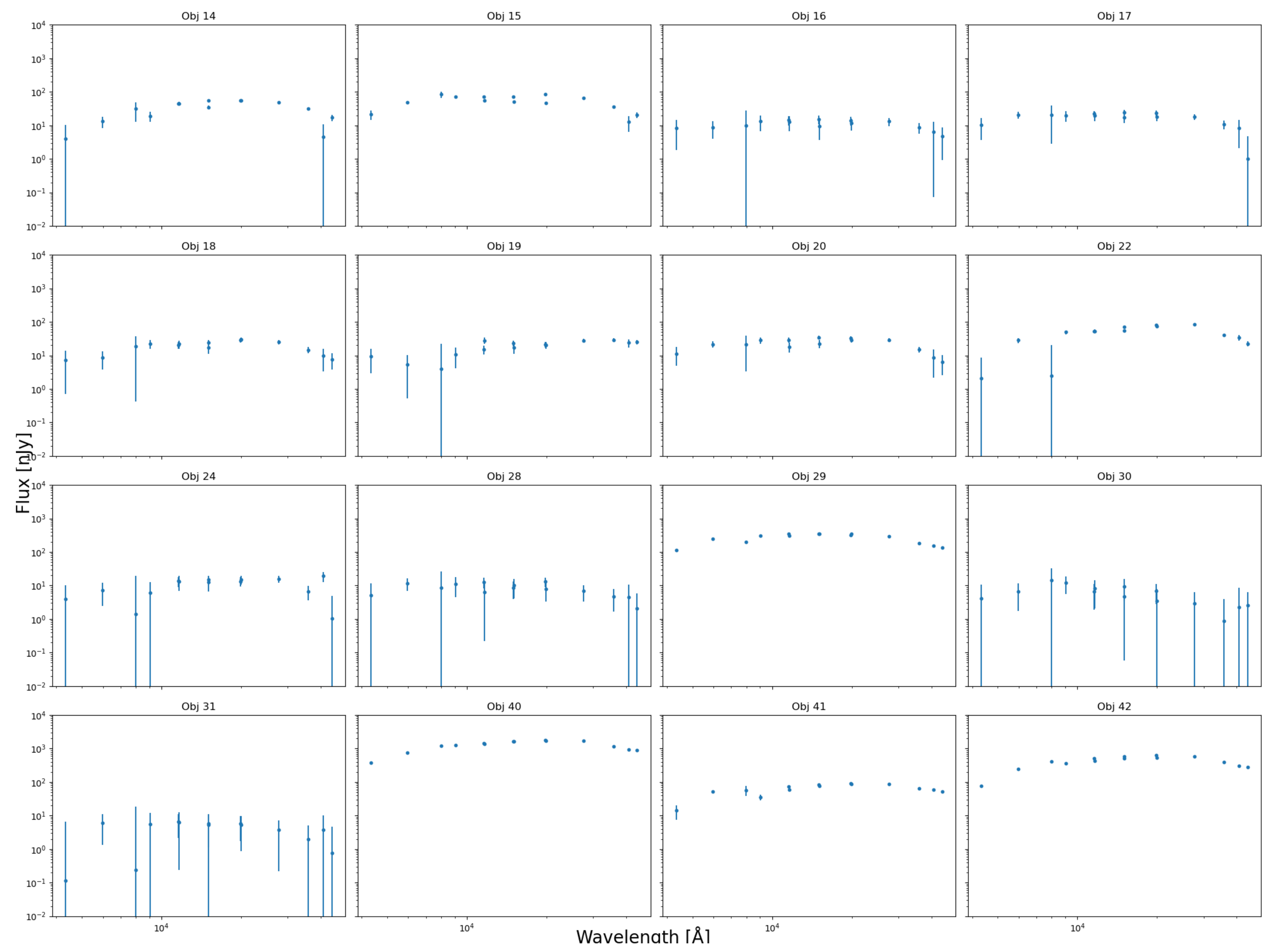

Fig. 4: Photometric plot of the objects highlighted in the segmentation map across all previously mentioned filters. The object id refers to the labels shown in the segmentation map.

The errors on the plots were calculated using the method of background estimation using empty apertures. First, empty apertures were selected in the image where all the sources were masked so that the apertures would only include the background. Next, the flux was calculated through all the apertures using the same photutils library. After putting all the fluxes in a histogram, a curve was fit to them. The uncertainty was chosen to be the standard deviation of the curve which resembles how much the background changes across the image. This process was done for all the filters.

4. SED Fitting

Dense Basis is an SED (Spectral Energy Distribution) fitting program with smooth non-parametric star formation histories. In other words, it's a tool used to recover accurate star formation history (SFH) information from galaxy spectral energy distributions (SEDs) [2]. Before applying the library, one must create an atlas of SEDs corresponding to well-motivated families of SFHs that effectively cover the space of all physical SFHs.This library can be used to fit SEDs on the photometric plots and then recover SFHs to obtain properties such as mass, metalicity, redshifts, etc... Since the error bars in the photometric plots are too big, the SED fitting will not be accurate and will cause high uncertainties in said properties.

5. Future work

The next step would be to fix the huge error bars on the photometric plots in order to obtain a better SED fitting using dense_basis. The goal of finding the redshift is to check whether all the object in the image are on the same plane or not. If they are, then this can be solid evidence that the two galaxies passed through each other which caused the trail of dust to be stripped from one of the galaxies and later form star clusters. Another possible explanation is Ram Pressure Stripping which investigates the stripping of dust from galaxies that enter galaxy clusters due to the hot gas in the intra-cluster medium. However, this theory wouldn't hold if the redshift of the galaxies were different from the z=0.44 redshift of the MACS0417 cluster. All these theories depend on the value of the redshift.

[1] Mathilde Jauzac et al. "The core of the massive cluster merger MACS J0417.5-1154 as seen by VLT/MUSE". In: *Monthly Notices of the Royal Astronomical Society* 483.3 (Dec. 2018), pp. 3082–3097. DOI: 10.1093/mnras/sty3312. URL: https://doi.org/10.1093%2Fmnras%2Fsty3312.

[2] Kartheik G. Iyer et al. "Nonparametric Star Formation History Reconstruction with Gaussian Processes. I. Counting Major Episodes of Star Formation". In: *The Astrophysical Journal* 879.2 (July 2019), p. 116. DOI: 10.3847/1538-4357/ab2052. URL: https://dx.doi.org/10.3847/1538-4357/ab2052.