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Compact sources in the A401–A399 galaxy cluster system observed at 90 GHz with the MUSTANG-2 camera

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ABSTRACT

We report the fluxes of 10 compact sources in 90 GHz maps of the galaxy cluster Abell 401 and the intercluster region between Abell 401 and Abell 399 from 66 h of observations with the MUSTANG-2 receiver on the Green Bank Telescope. All sources have been previously detected in other bands (IR or radio). The flux and central coordinates of each source are fitted with 2D Gaussian profiles and fluxes are compared with an aperture photometry method. Future observations over a larger area would be a unique tool to compare theoretical predictions of source counts at 90 GHz with measured data, as well as refining their spectral index and improve extrapolations to higher frequencies.

INTRODUCTION

Knowledge of compact source population properties in millimeter (mm) bands is still poor and mostly extrapolated from lower frequency data or derived from theoretical models (e.g., Massardi et al. 2010). Emission from extragalactic compact sources is a significant contaminant for high-resolution analysis of the CMB spectrum and can cause scattering in the scaling relationships between the integrated Sunyaev-Zel'dovich signal in galaxy clusters and cluster masses (Dicker et al. 2021). Several techniques have been proposed to remove detected compact sources from CMB maps (see, e.g., Barreiro 2005), but undetected sources create a background that must be removed using statistical information based on some priors, such as the differential number count (e.g., Pierpaoli 2003; Herranz et al. 2004). In this Research Note we describe point sources detected in deep 90 GHz observations with sub-arcminute angular resolution from the MUSTANG-2 receiver (M2; Dicker et al. 2014) at the Green Bank Telescope (GBT), a 100 m steerable radio telescope. Our work shows that a significantly increased set of observations could play a fundamental role in determining the properties of the mm compact source population.

OBSERVATIONS AND MAP-MAKING

Our observations with M2 were performed between December 2019 and February 2020 for a total of 66 h. M2 has 223 feedhorn bolometers and has been observing since 2018 under the GBT regular proposal calls. Its resolution is typically $9''$ (FWHM) and it has an instantaneous field of view of $4'.25$. We observed the galaxy cluster Abell 401 (A401) and the intercluster region between A401 and Abell 399 (A399) using the daisy scan observing strategy with several radii (from $2.5'$ up to $6.0'$). Flux and beam calibration were performed with planets. We analysed the data using the MIDAS pipeline which filters the data in Fourier space to remove low frequency atmospheric fluctuations and high frequency instrumental noise; see Romero et al. (2015) for further details. The resulting M2 map was used in Hincks et al. (2022) to study the level of fluctuations in the gas pressure in A401 and the inter-cluster region after point sources were removed from the data. Due to the different amount of time spent observing different regions of the map, we reached a sensitivity better than 2 µJy-arcmin^2 in the inter-cluster region and 9.5 µJy-arcmin^2 in A401 (Hincks et al. 2022).

The MIDAS pipeline returns three maps: the astrophysical filtered map, the respective noise image and the signal to noise ratio (S/N) map. We used two map versions with different Fourier space filters: a less aggressive version used a band pass filter between 0.08 and 51 Hz and more aggressive version used a band-pass between 0.2 and 12 Hz. Aggressive filtering suppresses extended sources since they have spatial scales that overlap with low frequency atmospheric fluctuations, but does not impact compact sources. This behavior was tested by injecting sources into MUSTANG-2 time streams and changing the frequency range of the filter. We expect that the flux of compact sources is conserved to within $\sim$10%.

POINT SOURCE DETECTION

We searched for compact sources in both S/N maps using a threshold of 4.5σ. In order to select only astrophysical sources and avoid pixels that could be corrupted by noise, we excluded the candidate sources where only a single isolated pixel satisfied the threshold condition. We also rejected sources that were only detected in one of the two maps without a NASA/IPAC Extragalactic Database (NED) counterpart within $0.2'$.

To determine the source properties, we fit the less aggressively filtered map with an elliptical Gaussian function within an $80''$ box centred on the source, using EMCEE (Foreman-Mackey et al. 2013), a Python implementation of the MonteCarlo Markov Chain (MCMC) algorithm designed by Goodman & Weare (2010). The fits had the following free parameters: the central coordinates of the compact source, the amplitude, the standard deviation along the semimajor axis as an estimator of the width, the eccentricity, the position angle of the major axis measured from celestial north to east, and a background modeled as a tilted plane. We also compute a source amplitude using forced aperture photometry within a radius of three times the best fit semimajor axis standard deviation, with the background measured in an annulus 5px wide ($10''$), starting $10''$ from the object aperture.

RESULTS AND DISCUSSION

We found 10 compact sources, all of which have an IR or radio counterpart listed on NED within $0.2'$, as well as counterparts in other radio surveys and observations. The sources together with the fitted properties are presented in Table 1.

Apart from one source (NVSS J025831+133417), the fluxes of these sources are below the sensitivity of current and near-term wide-survey CMB experiments. For instance, the upcoming Simons Observatory has a baseline, 5σ detection threshold for point sources of 7 mJy at 90 GHz (Ade et al. 2019). Our results demonstrate the potential for large-dish measurements of the mm sky to constrain low-flux, compact source populations relevant to CMB experiments.

Data availability and acknowledgements: The M2 maps used in this paper will be released on the Harvard Dataverse (Hincks et al. 2023). This research has made use of the ALLWISE dataset (Wright et al. 2019) hosted on the NASA/IPAC Extragalactic Database (NED), which is funded by the National Aeronautics and Space Administration and operated by the California Institute of Technology.

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Closest source	$f_{\mathtt{mcmc}}$[mJy]	$f_{\mathtt{ap}}$[mJy]	FWHM [$''$]	e	θ [deg]
WISEA J025807.66+131902.7*	0.46± 0.11	0.45± 0.09	11.48± 2.30	0.79± 0.21	39.60± 31.85
WISEA J025808.66+131749.9$^{\star *}$	0.67± 0.11	0.67± 0.10	13.64± 18.46	1.02± 0.22	30.31± 86.22
WISEA J025817.44+131548.1$^{\star *}$	0.47± 0.07	0.49± 0.05	9.59± 0.96	1.43± 0.20	−19.13± 11.14
NVSS J025817+131419$^{\ddagger \star *}$	0.75± 0.07	0.69± 0.07	10.79± 0.95	1.05± 0.14	10.81± 51.24
WISEA J025822.92+133149.2	0.80± 0.62	1.10± 0.47	10.49± 3.75	0.87± 0.58	−8.02± 239.68
WISEA J025831.68+131825.6	0.45± 0.08	0.36± 0.07	20.08± 3.04	0.55± 0.12	4.59± 9.99
NVSS J025831+133417$^{\ddagger \star *}$	25.31± 0.63	26.78± 0.58	12.44± 0.18	1.77± 0.03	−6.82± 1.00
VLASS J025837.77+131353.9$^{\dagger \ddagger \star *}$	1.04± 0.32	0.73± 0.20	9.20± 1.76	2.19± 0.44	−18.53± 9.31
WISEA J025841.57+133543.1	0.69± 0.20	0.98± 0.25	13.89± 1.75	1.18± 0.23	50.29± 13.26
VLASS J025914.77+132713.0$^{\dagger \star *}$	7.25± 0.97	7.11± 0.62	9.57± 0.86	1.89± 0.23	44.84± 4.59

Table 1. Best fit parameters and photometry of the compact sources. Fluxes are evaluated both from aperture photometry ($f_{\mathtt{ap}}$) and mcmc photometry ($f_{\mathtt{mcmc}}$). The additional source parameters are evaluated with the MCMC fit and are: the FWHM of the elliptical Gaussian's major axis, its eccentricity (e), and the position angle measured from celestial north to the east (θ). The first column contains the catalog name of the nearest source. If no radio counterpart is found in the selected surveys, the nearest WISE IR source is listed. †Source detected in VLASS data (https://cirada.ca/catalogues). ‡Source has RACS counterpart. * Source has VLA counterpart. * Source has MeerKAT counterpart Loi et al. (2023) (in preparation).

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