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MUSE ALMA Haloes Large Programme

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Data delivery document

1. Introduction:

Scientific goals: The interactions between gas and galaxies are of paramount importance to our understanding of structure formation. A fundamental element of such baryon cycle studies is a complete census of the condensed matter (stars and cold gas) in both galaxies and their immediate surroundings, the so-called circumgalactic medium. Of particular importance are the processes of converting molecular gas into stars and deciphering whether this <100K gas is tracing gas flows. The MUSE-ALMA Haloes survey has assembled probes of the neutral atomic gas H I, ionised gas and stellar component for a sample of 79 $z \sim 0.5$ galaxies. This is achieved by combining absorption line spectroscopy of background quasars to probe the low density circumgalactic gas with emission line tracers of both ionised gas and stars. This document accompanies the release of the data characterising the molecular phase of some of the MUSE-ALMA Haloes targets so as to reach a complete census of their condensed baryons. ALMA's unique millimetre coverage and high sensitivity is ideal to characterise the CO emission of these $z \sim 0.5$ H I-selected galaxies. By measuring the molecular mass, kinematics, gas flows and gas fractions, this project then: i) quantifies the role of molecular gas in H I-rich galaxies, ii) characterises the molecular phase of gas flows from morpho-kinematics analyses, and iii) establishes a census of the condensed baryons in the interstellar and circumgalactic media. Ultimately, these results will provide unique insights into the baryon cycle - a crucial component of galaxy formation.

The processed data include value-added data products generated by the team. The data products provided are:

- raw data files.
- one README file for each set of enhanced data uploaded (corresponding to a Group or Member OUS) in ascii (.txt) format following the observatory-provided template.
- a detailed Data Description Document accompanying the Group (or Member) OUS enhanced data package, which provides the user with a complete list of all the uploaded data products and a description of their content. The document includes the project title and project code and provides detailed descriptions of data files (and their provenance) contained in the delivery. This file provides sufficient detail for a prospective user to reproduce the data reduction and understand the multiple data sets within the products.
- the full combined cubes including the *.pbcor*. FITS files according to ALMA standards, the corresponding *.mask.*, and *.pb*. FITS files. The cubes are created with both natural weighting to maximize the signal-to-noise ratio and Briggs weighting with robust parameter set to 0.5. Both the spectral resolution of 15 km/s and the four-channel binned (corresponding to a spectral resolution of about 60 km/s) cubes which improved signal-to-noise are available. Cubes are supplied in FITS format.

2. Content of the data delivery:

The data delivery folder includes all the final products for each field, with the naming conventions following the ALMA observatory recommendations. The names start from the member Unique Identification number (UID) and are followed by the name of the quasar in the field. There are four datasets which are mosaic fields, with two or three pointings each. These are indicated as "mosaic" in the folder name. All observations were taken in ALMA band 4, but two sets we utilised band 6 and are dubbed “_B6_” in the directory naming convention.

All the images and datacubes for each specific field are included within each quasar field-based folder. The names of the files start with the member UID, followed by the proposal PI name (lp_celine) and the quasar field name, as recommended by the ALMA observatory. The naming convention next includes the chosen weighting scheme used to create the images. We use: 1) "nat" for natural weighting and 2) "briggs" for robust weighting with robust=0.5. The file naming convention next includes the spectral mode of the data product, including continuum images with the tag "mfs" and datacubes with "v*_cube". The number after 'v' refers to the velocity resolution of the datacube. The data release includes two distinct spectral resolutions: 1) one with a native 15 km/s dubbed “v15” and 2) one with a binned resolution of 60 km/s labelled “v60”. Furthermore, four of the quasar fields data products were self-calibrated. The filenames reflect this will the tag “selfcal”.

For each weighting scheme and spectral type, all the associated products are provided. These include the primary-beam corrected images (identified as *.pbcor.fits*), the masks (*.mask.fits*), and the primary beam data (*.pb.fits*). In the field of quasar "Q1229m021," strong and extended radio jets are observed. To improve fidelity of the products, we thus additionally applied the "mtmfs" clean algorithm to the "mfs" image.

Finally, each of the directory contains a README file termed *README.txt which contains the list of the delivered files and further describing the nature of each files.

The primary goal of the Large Programme was to search for the presence of molecular gas through CO tracers in galaxies previously detected at optical wavelengths with VLT/MUSE. Details of these so-called “primary” targets are provided in published paper: Bollo et al. 2026 (A&A, [2026arXiv260108633B](#)). We provide here again the full list of CO-detected primary targets. We note that given the depth of the ALMA data multiple additional emission and continuum detections are found in the data products. These “serendipitous” targets are the focus of an upcoming publication (Chen et al. 2026).

name	z	RA	DEC
Q0152m2001_12	0.78	28.112	-20.018
Q0454m220_4	0.48	74.037	-21.991
Q1211p1030_16	0.89	182.918	10.503
Q1229m021_6	0.83	187.993	-2.403
Q1229m021_8	0.83	188.002	-2.397
Q1342m0035_4	0.53	205.694	-0.597
Q1345m0023_13	0.61	206.447	-0.389
Q1431m0050_10	0.61	217.934	-0.838
Q2131m1207_5	0.43	322.899	-12.116

3. The methods of data processing:

The data reduction and imaging largely followed the ALMA observatory guidelines. Specifically, we extract the calibrated measurement sets (ms) produced with the Common Astronomy Software Applications (CASA, version 6.5.6) by the observatory. In addition, we apply self-calibration when possible and produce the images and datacubes with different weighting schemes and channel widths. In six of the observed fields, the background quasars are bright enough at mm frequencies (≥ 4 mJy) to perform self-calibration. Self-calibration corrects for short-term phase and amplitude variations, resulting in a marked improvement in the sensitivity hence dynamical range of the final images. We first clean the continuum image of the quasar field interactively to generate the clean model for self-calibration. During the first round of interactive cleaning, we clean the quasar based on the point source assumption. Then, we derive a phase-only calibration with various time intervals ranging from 30 seconds to 4 minutes, depending on the brightness of the quasar. We select the time intervals based on the improvements in the final imaging products. We also apply amplitude self-calibration if the quasar is brighter than 20 mJy and accepts the signals down to 5σ when constructing the clean models. During self-calibration, the calibration tables are generated with the task `gaincal` and apply to the pipeline-calibrated measurements using `applycal`. After self-calibration, the RMS sensitivity is improved by factors ranging from 1.1 to 7.6, compared to the ones without self-calibration. Besides, our manual self-calibration also improve the sensitivity by a factor of about 1.2 compared to the automated observatory-based self-calibration pipeline products. In one of the fields, Q2131–1207, the quasar is bright leaving some artifacts across the field-of-view. We use the CASA task `uvcontsub` to remove the continuum contamination from the bright quasar while excluding the line-emitting channels of our primary targets.

We then image the (self-)calibrated visibility into continuum images and 3D images (datacubes) with the CASA task `tclean`. For four of the quasar fields, several pointings are used to maximise the spatial coverage of the targets with known sky positions. The images of the mosaic fields are created by setting the `gridding` to "mosaic". The images are created with two different weighting schemes. The "natural" weighting is used to maximize the detection sensitivity, and the "Briggs" weighting (`robust=0.5`) is used to achieve an optimal balance between sensitivity and spatial resolution. We chose two distinct velocity resolutions. The 15 km/s resolution corresponds to the intrinsic spectral resolution. We further apply a spectral binning of four channels to improve the signal-to-noise ratio, resulting in a spectral resolution of 60 km/s. As a result, four different types of images and datacubes are produced, for each of the two weighting schemes and each two of the spectral resolution choices. The natural weighting with the 60 km/s products is better suited for searches for line emissions, while the Briggs weighting with different velocity resolutions is better suited for detailed kinematic analysis of the targets with strong line emissions. Full details can be found in Peroux et al. 2026, A&A).

4. The quality assessment:

We first conducted a pipeline-based quality assessment for all the standard calibrations and did not find any noticeable problems. In addition to the standard pipeline, we applied our own manual self-calibration. The phase and amplitude solutions are stable based on the chosen time interval, and the final total flux densities of the science targets are also stable. The final self-calibrated images are consistent with the theoretical sensitivity. These data have already been used for science analysis so that they are fully validated (Bollo et al. 2026, A&A, [2026arXiv260108633B](#)).