

# ESO Phase 3 Data Release Description

## Abstract

The APEX Low-redshift Legacy Survey for MOlecular Gas (ALLSMOG) is a survey of CO  $J=2-1$  (rest frame frequency, 230.538 GHz) line emission in a sample of 88 galaxies in the local Universe (programme no. E-192.A-0359). This sample is well characterized in terms of several derived and measured physical properties (star-formation rates, stellar masses, gas-phase metallicities, and atomic HI gas masses). The primary goal of ALLSMOG is to add information on the cold molecular gas content of these galaxies derived from the low- $J$  CO line emission in order to determine the impact of the gas content on the inferred galaxy properties. The programme lasted for five semesters (P92 to P96) and consumed 327 hours of APEX observing time. The goal of the survey was to reach a CO  $J=2-1$  line peak-to-rms ratio of,  $S/N > 3$  for the detections, and an uniform rms of 0.8 mK (31.2 mJy) per 50 km/s channel for the non-detections. Multi-epoch observations of the same source were merged together to produce a single CO  $J=2-1$  spectrum for each target. This document describes the data release of the final reduced ALLSMOG dataset, including both detections and non-detections. The data release and analysis is described in more detail by Cicone et al. 2017, A&A. Previously published ALLSMOG survey papers include:

“ALLSMOG: an APEX Low-redshift Legacy Survey for MOlecular Gas - I. Molecular gas scaling relations, and the effect of the CO/H<sub>2</sub> conversion factor”: M. Bothwell, J. Wagg, C. Cicone, R. Maiolino et al. 2014, MNRAS, 445, 2599

“Molecular gas as the driver of fundamental galactic relations”: M. Bothwell, R. Maiolino, Y. Peng, C. Cicone, H. Griffith, J. Wagg, 2016, MNRAS, 455, 1156

“Galaxy metallicities depend primarily on stellar mass and molecular gas”: M. Bothwell, R. Maiolino, C. Cicone, Y. Peng, J. Wagg, A&A, 595, 48

“Galaxy metallicities depend primarily on stellar mass and molecular gas mass”: M. Bothwell, R. Maiolino, Y. Peng, C. Cicone, J. Wagg, 2016 A&A 595, 48

The ALLMSOG team website can be found here: [www.mrao.cam.ac.uk/ALLSMOG/](http://www.mrao.cam.ac.uk/ALLSMOG/)

## Overview of Observations

The ALLSMOG observing strategy has been aimed at exploiting the ‘poor weather’ observing conditions at the Chajnantor Plateau. Figure 1 shows the distribution of time spent observing under various weather (i.e. precipitable water vapour, PWV) conditions throughout the 327 hours duration of our programme. The broad range in LST values spanned by ALLSMOG targets encouraged the scheduling of the project as a filler programme, which eventually resulted in a significant amount of observing time spent during very dry conditions (PWV < 2 mm).

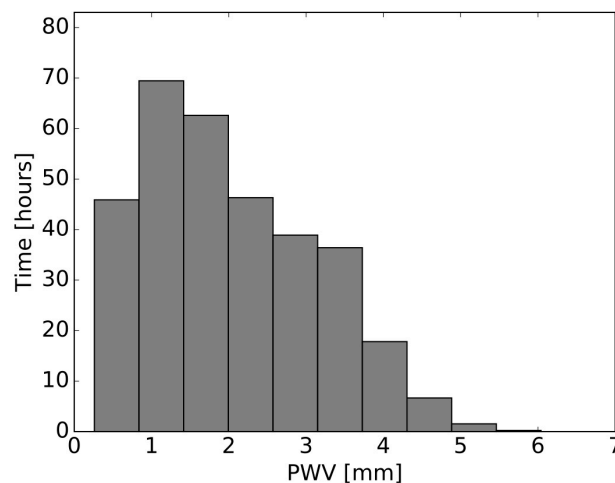


Figure 1 – Histogram of the distribution of precipitable water vapour values during the ALLSMOG observing campaign. From Cicone et al. (2017).

The APEX-1 230 GHz receiver was used to observe 88 galaxies over five ESO semesters between and including P92 and P96. Data were taken between July 10, 2013 and December 31, 2015. The total bandwidth of the APEX-1 backend covers 4 GHz, which is achieved by using two 2.5 GHz spectrometer units overlapping by 1 GHz. This bandwidth is more than sufficient to ensure that no CO line emission would be missed in the case of any discrepancy with the optical redshift. The system temperature of APEX-1 across the band used to observe the CO line emission is  $\sim 200$  to 250 K. The wobbler was used to observe our science targets with a 60 arcsecond chop in position during repeated six minute ON-OFF scans at a rate of 1.5 Hz. Each galaxy was observed at elevation angles between 30 and 80 degrees until either a clear detection of the CO line emission was obtained (line peak – to- rms ratio of,  $S/N > 3$ ) or a rms sensitivity of 0.8 mK per 50 km/s channel was reached.

Pointing was checked every hour using bright, nearby point sources, while the focus was checked on planets every three hours and after significant changes in the atmospheric conditions (e.g. after sunset and dawn). Calibration was performed using the online data calibrator program which corrects for the atmospheric opacity so that the spectra are output in units of antenna temperature corrected for atmospheric loss,  $T_A^*$ . For the observations taken between March and June 2014, the  $T_A^*$  values produced by the online calibrator had to be multiplied by a small re-calibration factor (0.8 to 0.9, depending on the exact observing date and frequency tuning) to account for a calibration error introduced by a hardware intervention in March 2014. We estimate that the absolute flux scale should have an accuracy between 8 and 12%, depending on the date of observation. In the header, the value of FLUXERR is set to 20% in order to be conservative.

## Release Content

Galaxies in our sample have been identified in the SDSS DR7 catalogues, and subsequently characterized by groups at the Max-Planck-Institut Fur Astrophysik (MPA) and JHU to derive estimated star-formation rates, stellar masses, and metallicities (Kauffmann et al. 2003, MNRAS, 341, 54). Our 88 APEX-1 targets were selected from the MPA-JHU catalogue to include galaxies:

1. Classified as 'star-forming' according to their location on the  $\log([\text{OIII}]/\text{H}\beta)$  vs  $\log([\text{NII}]/\text{H}\alpha)$  diagram.
2. with stellar masses,  $8.5 < \log(M_*/M_{\text{sun}}) < 10.0$ ;
3. with declinations less than  $+15^\circ$  (to ensure that they are observable from the Southern APEX site);
4. with accurately measured metallicities  $12 + \log(\text{O}/\text{H}) > 8.5$ , according to the Tremonti et al. (2004) metallicity calibration;
5. lying in the redshift range,  $0.01 < z < 0.03$ ;
6. with an existing HI observations from the literature.

Tables containing the full list of targets, their physical properties and a general description of the APEX CO data can be found in Cicone et al. (2017).

## Release Notes

### Data Reduction and Calibration

**Data reduction and analysis:** The spectra were analysed using customized scripts written for the GILDAS/CLASS software package. The process consisted of first combining the two 2.5 GHz spectral segments obtained from the two different spectrometer units into a single spectrum covering 4 GHz of bandwidth. Each spectrum was examined to determine if any obvious instrumental spectral baseline structure was present, and then any poor quality or corrupted spectra were removed from the dataset. As a consequence of this quality check, 17% of the data were flagged. A first order baseline was fitted and removed from each spectrum by masking the spectral region corresponding to the velocity range of,  $(-300, 300)$  km/s around the expected CO line. All spectra belonging to observations targeting the same source (sometimes observed in different dates) were then averaged together and smoothed to the desired spectral resolution. In the majority of the cases we adopted a final spectral resolution of 50 km/s, but for a few cases of particularly narrow or broad lines we used a different binning to optimise the S/N of the detection. A final baseline fit and subtraction was performed on this total integrated spectrum, where the width of the central window masked from the fit was adjusted based on the width of the observed CO line. The resulting spectra were then converted from the calibrated  $T_A^*$  scale to the flux density scale (Jansky) by using the APEX-1 conversion factor of 39 Jy/K. For further details on the data reduction and analysis procedure, we refer to Cicone et

al. (2017).

**Detection criteria:** The significance of the detection was determined by fitting one or more Gaussian functions to the observed CO line profile. In all galaxies but one (NGC2936) the profile was well fitted by a single Gaussian. The sources where the line was centred on the expected frequency and with a line peak signal-to-noise,  $S/N > 3$  were classified as secure detections. Among the marginal detections ( $S/N \sim 3$ ), we accepted only those where the central velocity of the putative CO line was consistent with the redshift expected from the HI 21cm line detection. Further explanation is provided in Cicone et al. (2017).

**Aperture corrections:** In the data release paper (Cicone et al. 2017) we provide the correction factors to account for possible flux losses due to any potential CO line emission lying outside the APEX beam ( $\sim 27$  arcsec at 230 GHz). These were estimated following the method described by Bothwell et al. (2014). The resulting corrections are typically very low, with a median value of 2%.

## Data Quality

**Reduction Quality Control:** Every spectrum was examined in order to verify that the spectral baselines did not suffer from any non-Gaussian features. We rejected poor-quality spectra based on three different factors: (i) the presence of clear features or ripples visible by eye; (ii) high ( $\gg 1$ ) ratios between the measured rms noise level and the theoretical value calculated using the system temperature and the integration time; and (iii) high values of the modified Allan variance factor, defined in Cicone et al. (2017), which quantifies how much the rms noise level decreases after rebinning with respect to the theoretical value, which assumes a random white noise. This quality check resulted in the flagging of  $\sim 17\%$  of the data.

## Known issues

There are no known issues with the data in the present release.

## Previous Releases

N/A.

## Data Format

### Files Types

This release contains 88 1-dimensional spectra, containing a single reduced APEX-1 galaxy spectrum each, named: *SOURCE.fits*, where the 'SOURCE' name matches the nomenclature adopted in the data release paper (Cicone et al. 2017).

The spectra are contained in three columns:

7. Frequency, label "FREQ", unit GHz, format 4-byte FLOAT
8. Flux density, label "FLUX", unit mJy, format 4-byte FLOAT
9. Flux density error, label "ERR", format 4-byte FLOAT

The OBJECT keyword in the FITS files matches the object ID as specified by the observer in the data header and log files. This is usually an abbreviated version of the 'SOURCE' name used in the paper, or in a few cases it corresponds to a different galaxy nomenclature.

EXPTIME in the FITS files indicates the on-source time also listed in Col 3 of Table 1 of Cicone et al. (2017). The on-source time includes only the data used to produce the final spectrum (hence it does not include technical overheads or flagged data).

The SNR keyword in the FITS files corresponds to the ratio between the total velocity-integrated line flux (in units of Jy km/s), as estimated from a Gaussian fit, and the associated error. We note that this is different from the line peak signal-to-noise ratio. SNR has been set to '0' for non-detections, while these data provide useful upper-limits.

## Acknowledgements

*Any publication making use of this data, whether obtained from the ESO archive or via third parties, must include the following acknowledgement:*

- "Based on data products created from observations collected at the European Organisation for Astronomical Research in the Southern Hemisphere under ESO programme 192.A-0359"

*If the access to the ESO Science Archive Facility services was helpful for your research, please include the following acknowledgement:*

- "This research has made use of the services of the ESO Science Archive Facility."

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