Revealing Cold Molecular Gas Reservoirs in Distant, Dusty Starbursts

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Abstract

We propose to use ATCA in the 7 mm band to detect cold molecular gas in up to 60 submm-selected galaxies. Our project will roughly triple the number of non-lensed SMGs with detections of the cold molecular gas reservoir, demonstrating its legacy value. We aim to characterize the general properties of the cold molecular gas in SMGs: mass, gas depletion time scale, star formation efficiency and dynamics. These low-J CO measurements are indispensable to build up the CO spectral line energy distributions and thus derive the gas densities and temperatures, thereby getting insight into the molecular gas excitation. This data will help us to understand the early phases of the growth of massive galaxies and constrain galaxy evolution models.

Scientific Aims

Since their initial discovery (Smail et al. 1997), submillimeter galaxies (SMGs; see the review by Casey et al. 2014) have become an important element of our understanding of cosmic galaxy formation and evolution. Selected in the rest-frame far-infrared (FIR), these massive, dusty sources have intense star formation, with rates of a few hundred to several thousands solar masses per year. The peak of their redshift distribution lies at around $z = 2.2$ (Chapman et al. 2005) consistent with the peak of the star formation and black hole activity of the universe. Ultraluminous infrared galaxies (ULIRGs) are responsible for roughly half of the cosmic IR luminosity density at those redshifts (Magnelli et al. 2013), suggesting SMGs play a vital role in galaxy evolution.

Molecular gas studies of SMGs provide unique insight into the physical properties of these systems, e.g. the luminosity of the CO line provides an estimate of the molecular gas reservoir available for star formation. Detailed studies of these distant dusty starbursts are still rare, mainly due to the large amount of time required for a molecular line detection. Only a few tens of unlensed SMGs at $z \gtrsim 1.5$ have been detected in CO (e.g. Bothwell et al. 2013; Carilli & Walter 2013). We note that the molecular gas reservoir of this source population has been mainly targeted through mid-J CO transitions. However, the ground transition CO(1-0) gives us the most direct link to the total molecular gas mass and also is the spatially most extended component (Ivison et al. 2011), thus providing us with a complete census of the cold molecular gas reservoir.

We propose to observe the cold molecular gas in a large number of SMGs at $z \sim 1.5 - 6.5$ with ATCA in the 7 mm band. The primary aim of this project is to measure the gas mass, dynamical mass and star formation efficiency of them. In particular, gas and dynamical mass measurements will enable us to derive a gas consumption timescale, a gas-to-dynamical mass fraction, and a total baryonic mass for the system in combination. From the measured $L'(CO)/L(FIR)$ luminosity ratio (i.e. M(H2)/SFR), we will estimate the time-scale of the starburst activity in these sources, or equivalently the inverse of the ratio will be used to quantify the star-formation efficiency (e.g. Tacconi et al. 2010; Bothwell et al. 2013). Any resolved line structure potentially allows us to test for the triggering mechanism, i.e. merger vs secular disk. Furthermore, these low-J CO measurements are crucial for "anchoring" the CO spectral line energy distributions (SLEDs), which are used to model the gas density and temperature of the SMGs (Narayanan & Krumholz 2014).

Number of Objects and LST range

In total we aim to observe 60 unlensed sources all of them having reliable spectroscopic redshifts, with priority given to high-J CO detected sources with ALMA. Up to now, only about 20 unlensed SMGs have CO(1-0) detections, mainly at $z = 2$, and detections at $z = 4$, CO(2-1), are still quite scarce. Thus, our project will triple the number of sources with detections of the cold molecular gas reservoir. Furthermore, this huge number allows us to break them into three samples of 20 to look at trends with e.g. redshift, line width, star formation rate or stellar mass.

The majority of our SMG targets will come from the APEX-LABOCA survey LESS (Weiss et al. 2009) which covers the Extended Chandra Deep Field South (ECDFS; RA:03:32:29, DEC:−27:48:47).

However, in order to allow flexible scheduling over each semester (whole year) we plan to include targets from other surveys such as the well-studied fields UDS (RA:02:18:00, DEC:−4:30:00) and COSMOS (RA:10:00:00, DEC:+2:12:00), both covered by SCUBA-2 surveys. Thus, in both semesters we should be able to observe our targets in night-time. We will combine the huge ATCA efforts with our on-going ALMA campaign which provides us with high-J CO transitions, [CII] line detections and dust maps. From these data products we derive velocity fields and gas/dust morphologies. E.g. for the SMGs in ECDFS, we have exisiting ALMA confirmed identifications and deblended infrared luminosities. Similar analysis we will soon do for sources in UDS (and hopefully COSMOS).

Frequency

We will carry out our observations in the 7 mm band (30–50 GHz). Within this frequency range we will reveal the cold molecular gas reservoir either via the CO(1-0) transition for SMGs at $1.3 < z < 2.8$ or via the CO(2-1) transition for dusty starbursts at $3.6 < z < 6.5$.

CABB mode

We will conduct the observations in the "default" low-resolution spectral-line mode (2×2 GHz bands with 2048 channels of 1 MHz). Thus, we will cover a velocity range of ∼16,000 km/s per 2 GHz IF and ∼8 km/s resolution for $z = 2 - 4$ sources.

Array Configuration

We request the compact hybrid ATCA configurations H168 or H214, but H75 is also suitable. For selected sources with a bright CO detection we also aim to re-observe with a 750 m configuration to spatially resolve the gas.

Observing Strategy

Based on previous experiences, we prefer to observe in 8 hrs blocks with sources at greater than 30 degree elevation to minimise air mass. Calibrations such as bandpass, phase and pointing will be done during each run. Flux calibration will be carried out on a regular basis.

Required Sensitivity

We aim to detect CO(1-0) at a secure 5 sigma level in at least 2 independent channels. Assuming a typical linewidth of FWHM 500 km s^{-1} for SMGs and the $L(FIR)$-L'CO relation of Ivison et al. (2011), we need to reach a noise level of $\sim 5\times10^9$ K km s^{-1} pc^2 when binning the data to 250 km s^{-1}. This requires a noise level of ∼0.05 mJy/beam per 250 km s^{-1} channel for a target at $z \sim 2$. According to the ATCA online sensitivity calculator, this requires 24 hours of on-source integration time. This is consistent with our team's extensive expertise in using the ATCA 7 mm band for high-z CO studies (e.g. Huynh et al 2014; Emonts et al 2014). Accounting for typical 7 mm overheads of 40%, we therefore request 40 hours for each targets. An additional 20 hrs is required for the detection of fainter (in L_{IR}) SMGs. Thus, the observing time including overheads will range between 40 to 60 hrs per source. After each run, we will reduce the data and in case of detection, the observing time would be reduced. Systematics are minimised and spectra more reliable if the data is combined from observations on different days.

Time Request

In total we would ask for up to 3000 hrs of ATCA time including overheads and spread over five years. Within this huge time request we should get roughly 60 reliable detections.

Team Members and Skills

Several team members — H. Dannerbauer, M. Huynh, B. Emonts, M. Mao, N. Seymour — have extensive experience with ATCA observations in the 7 mm band of CO in high-z sources such as SMGs. Their expertise includes data reduction and interpretation of the data cubes, resulting in a number of published manuscripts in the past years. The expected data are manageable by our team. We note that the PIs of LESS (I. Smail and F. Walter) and several experts on (multi-wavelength) studies of SMGs complement our team, guaranteeing high-impact output of our ambitious study of SMGs with ATCA.

References: • Bothwell et al. 2013, MNRAS, 429, 3047 • Carilli & Walter, 2013, ARA&A, 51, 105 • Casey et al. 2014, PhR, 541, 45 • Chapman et al. 2005, ApJ, 622, 772 • Emonts et al. 2014, MNRAS, 438, 2898 • Huynh et al. 2014, MNRAS, 443, 54 • Ivison et al. 2011, MNRAS, 412, 1913 • Narayanan & Krumholz, 2014, MNRAS, 442, 1411 • Smail et al. 1997, ApJL, 409, 5 • Tacconi et al. 2010, Nature, 463, 781 • Weiß et al. 2009, ApJ, 702, 1201 •