Molecular Gas Content of SMGs in a z=2.47 Starbursting Protocluster

Jaclyn Champagne[1], Caitlin Casey[1], Christopher Hales[2,3], Peter Capak[4], David Sanders[5], Nick Scoville[6]

[1]University of Texas at Austin, [2]Newcastle University, [3]National Radio Astronomy Observatory, [4]Spitzer Science Center/IPAC, [5]IfA, University of Hawaii, [6]California Institute of Technology

Introduction

A massive galaxy cluster progenitor spanning 0.5° on the sky at z=2.47 was first identified serendipitously during a Keck MOSFIRE redshift survey of SCUBA-2-detected submillimeter galaxies (SMGs) in the COSMOS field (Casey et al. 2015). The structure, spanning a narrow redshift range of Δz=0.02, is characterized by an overdensity of SMGs assumed to be in a collapsing protocluster, and we focus on two particularly concentrated regions: one along the line of sight, and one in a transverse configuration along the sky. We observe these areas of submillimeter excess in two pointings with the Jansky Very Large Array (JVLA): one centered on SMG 450.58 and the one here presented focused on 450.28 and 450.16 as named for their SCUBA-2-identified sources in Casey et al. 2013 (COSBO3 in Bertoldi et al. 2007 and AzTEC/C6 in Aretxaga et al. 2011).

We present followup observations using the JVLA Ka band to search for CO(1-0) emission in these sources. CO(1-0) is the most robust tracer of total molecular gas and thus star formation rates in star-forming galaxies, as it does not introduce as much uncertainty as more highly-excited lines of CO. Characterizing the molecular gas content in the constituent submillimeter galaxies in this protocluster serves to constrain its potential for current and future star formation, and answer questions about how massive clusters coalesce.

An unanswered question in the field of protocluster formation is the effect of the overdense environment on the capacity for star formation in member submillimeter galaxies: do they form their stars all at once and become quiescent, or is there a source of additional gas for continued star formation? We aim here to constrain the molecular gas content in different regions of the protocluster and compare this that of galaxies in the field. We report in total 15 candidate detections in this ~1.2' field: four coincident with Wang et al. (2016), seven sources previously identified as DSFGs or LBGs in Casey et al. 2015, and four serendipitous detections.

Candidate Detections

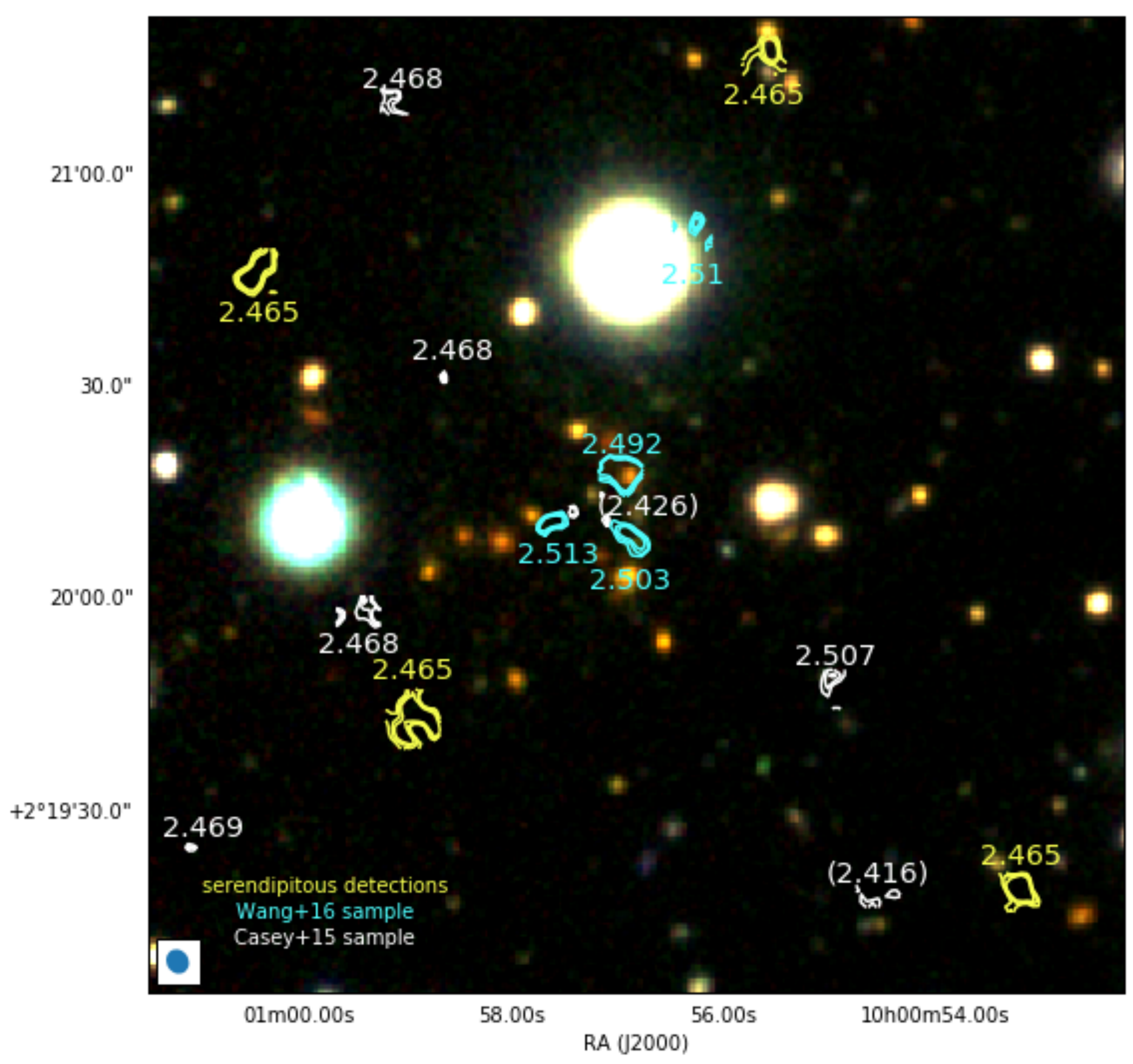
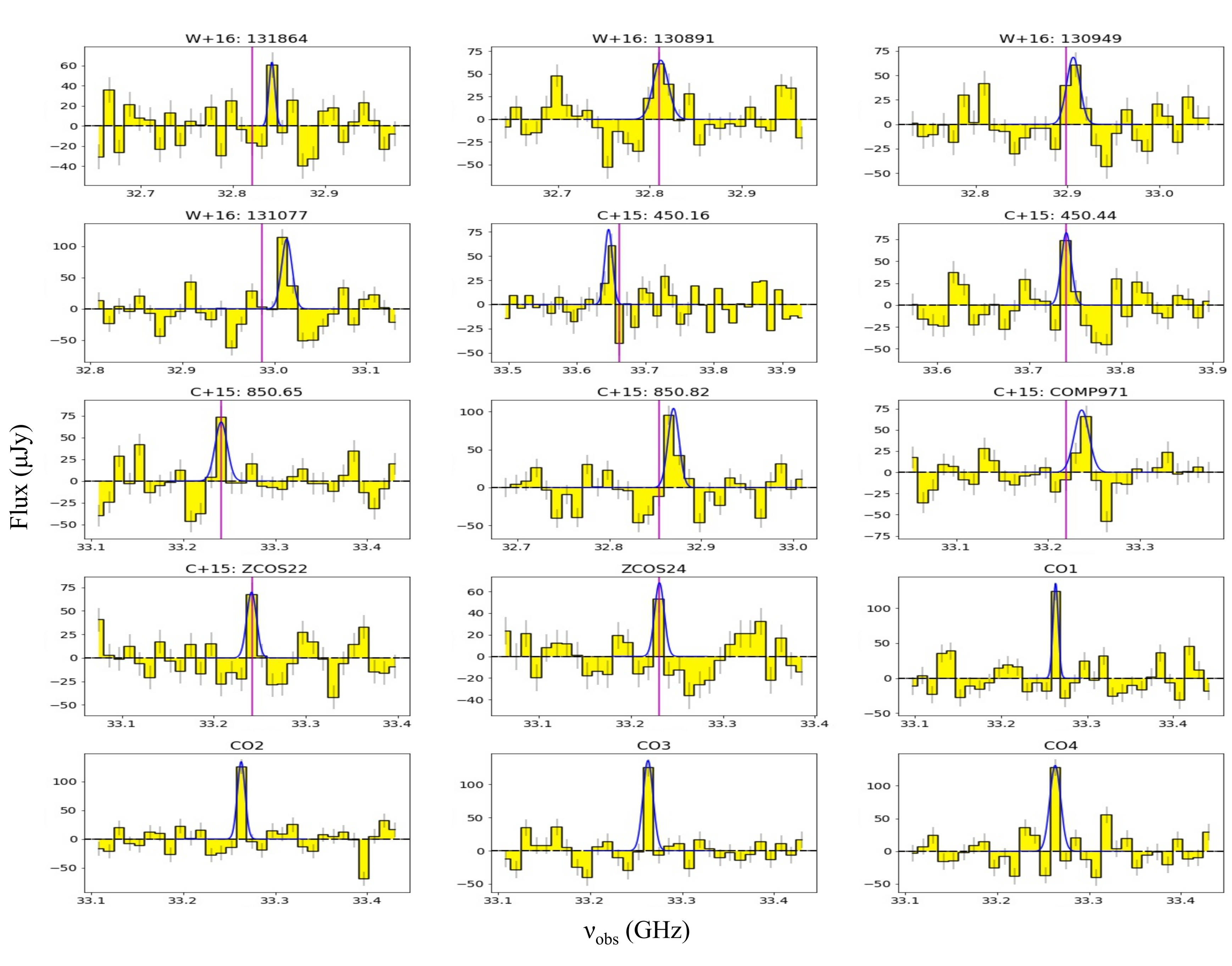


Figure 1. The near-IR background image is a 3'x3' cutout from UltraVISTA (Y, J, and Ks bands); the overlaid contours are the moment-0 CO(1-0) candidate detections from the JVLA. The yellow contours correspond to our serendipitous detections; the white contours correspond to previously confirmed LBGs and DSFGs in Casey et al. (2015); the blue contours correspond to coincident detections with Wang et al. (2016). The contours begin at 3σ; the continuum RMS level in these maps is ~100 μJy. The numbers correspond to calculated redshifts; parentheses indicate that it is not physically associated with the protocluster.

Figure 2. JVLA spectra with Gaussian fits (blue) for each of the fifteen candidate sources, denoted for (W)ang+2016, (C)asey+15, and CO for serendipitous detections. The magenta line denotes the expected redshift of the CO(1-0) line based on its previously reported spectroscopic redshift.

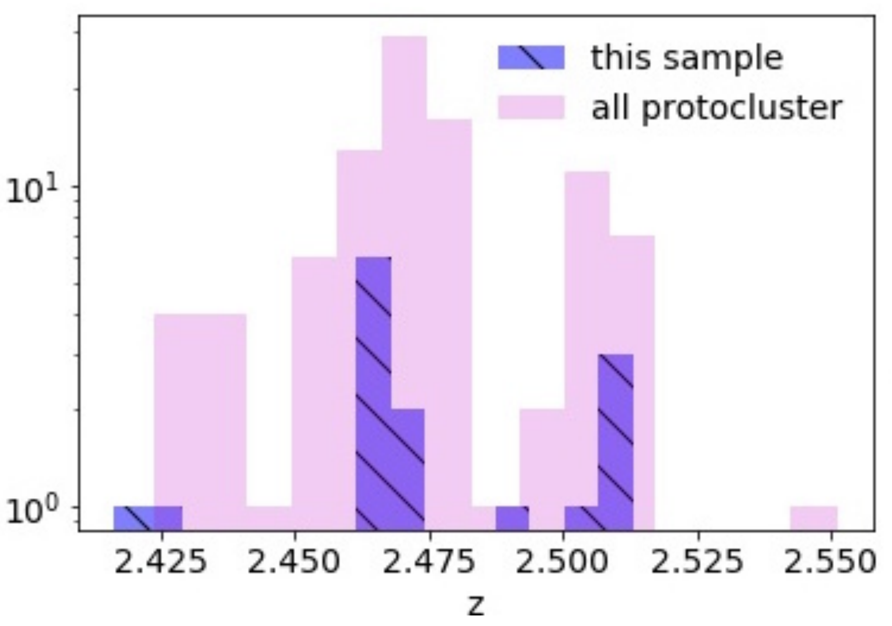


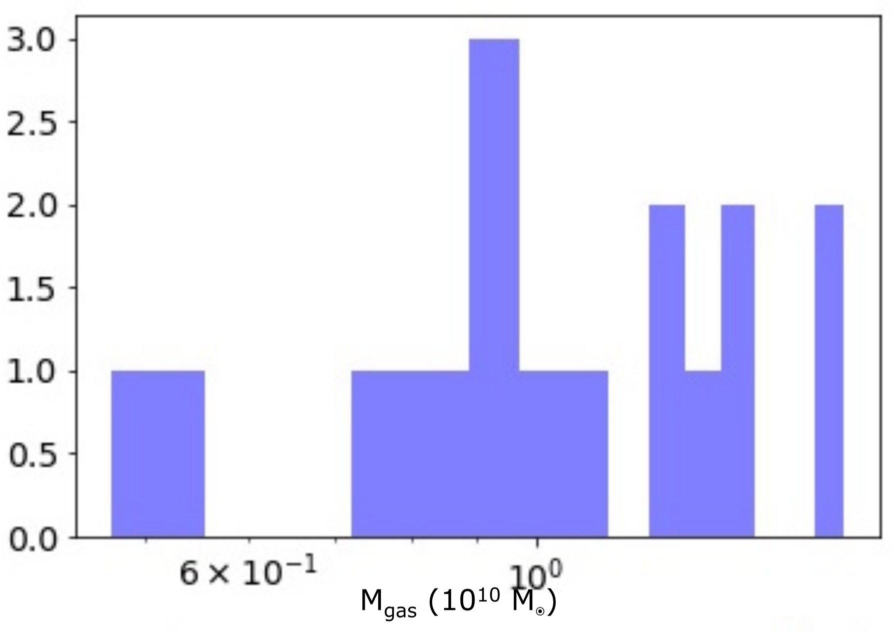
Virialized Protocluster Core or Line-of-Sight Filament?

A recent paper by Wang et al. (2016) reports 16 candidate CO(1-0) detections in an overlapping pointing with this data, with a slight spatial offset and about half the integration time as this work. We report a number of coincident detections – of the Wang sample, we confirm five detections in total (one previously identified in the Casey sample). In addition, however, Wang et al. reports a significant extended X-ray detection as proof for a virialized core, which would imply the most distant massive virialized cluster to date. However, we argue that this X-ray emission could be inverse Compton scattering caused by a ghost radio galaxy (A. Fabian, priv. comm.; Fabian et al. 2009), and it is likely that this cluster progenitor is not virialized since there remains a fairly wide redshift range among these candidate sources. Therefore, we are most likely observing a LOS filament of a still-collapsing protocluster.

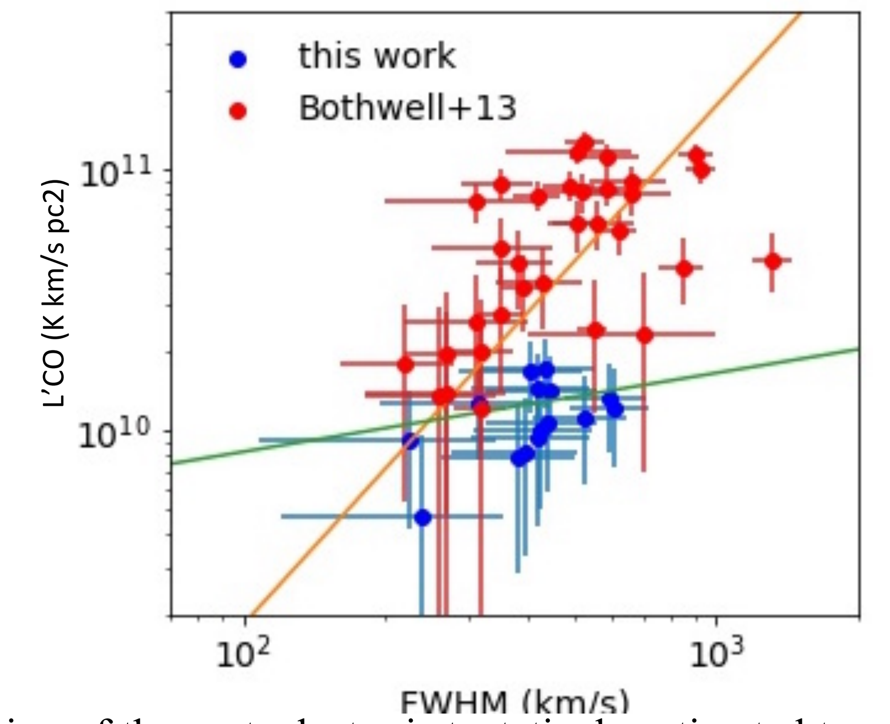
Analysis

So far we have discovered 15 candidate detections in this small region of the COSMOS field, in a confirmed overdensity of dusty star-forming galaxies. The following figures offer a distribution of some physical properties of these candidates, including their redshifts, CO line luminosity vs. FWHM, and finally, the total molecular gas mass (assuming a conversion value of α = 1.0 $M_\odot$ / K km/s pc^2 (Carilli & Walter 2013)). The median redshift of this sample is 2.468, in line with the initial protocluster detection at z=2.47; see z-distribution in Figure 3. We also show, in Figure 5, a relationship between the FWHM and the calculated line luminosity, as in Bothwell et al. (2013), which is focused on field SMGs. Bothwell et al. calculates a power law fit with index 1.98, while in this work we calculate a much shallower index of 0.301. This large offset may be the effect increased turbulence of gas infall and star formation caused by an overdense environment.





Figures 3-5. Top left: a distribution of redshifts in all confirmed protocluster sources thus far. The hatched histogram shows these JVLA detections while the solid shows sub-mm and optically-confirmed sources. Top right: a distribution of the calculated molecular gas masses in each of these fifteen sources. Bottom: L'CO vs. FWHM for the new candidates (blue) plotted with field SMGs from Bothwell et al. (2013), with respective power law fits of index 0.301 and 1.98.



The total molecular gas mass in this sub-region of the protocluster is tentatively estimated to be ~2 x 10^{11} $M_\odot$. The gas depletion timescale, defined as τ_{depl} = M_{gas}/SFR, denotes how long a galaxy could continue its current rate of star formation given its current gas mass; while this could be informative for extreme starbursting (and thus short-lived) systems, it does not take into account the possibility of additional gas feeding at different evolution points, especially in the rich environment a collapsing cluster might offer. However, gas feeding is not indefinite, so one can assume an upper limit on the stellar mass of a cluster member galaxy to be ~10^{12} $M_\odot$ (van der Burg et al. 2013), and thus make a statement about the timescale on which these galaxies can sustain rapid star formation.

Since there is significant source confusion in the original sub-mm maps, we do not yet have accurate SFR estimates for these sources. However, to highlight an example, 450.28 has a SFR of ~126 $M_\odot$/yr, and the average gas mass of these galaxies is ~1.1 x 10^{10} $M_\odot$. This implies a maximum timescale for available gas of ~90 Myr given no additional feeding, but with additional gas infall this rate of star formation could proceed for several Gyr. The evolutionary phase of a galaxy in which it is so submillimeter-luminous is assumed to be short-lived, and this protocluster is likely undergoing a relatively brief starbursting period. We are exploring a more direct comparison between the z~0 cluster stellar mass function and SMG star-formation history to constrain the simultaneity of starbursts in overdense environments.

References

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