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The Atacama Large Millimeter Array: Imaging Gas and Dust in Distant Galaxies

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Abstract. The Atacama Large Millimeter Array (ALMA), a project of the National Radio Astronomy Observatory and the European Southern Observatory, will be built over the coming decade in Northern Chile. ALMA will be a revolutionary telescope, operating at millimeter and submillimeter wavelengths. Detailed imaging at these wavelengths will be a major step for astronomy, making it possible to study the origins of galaxies, and the state of gas and dust in forming and interacting distant galaxies. Here we present a simulated ALMA medium deep image.

1. Introduction

The Atacama Large Millimeter Array, or ALMA, a project of the National Radio Astronomy Observatory and the European Southern Observatory and their partner countries and institutions, will be built over the coming decade in Northern Chile. With over 7000 m^2 of collecting area comprised of 64 12m antennas arrayed over baselines up to 14 km in extent, ALMA will provide images of unprecedented clarity and detail. One revolutionary feature of ALMA will be its ability to combine interferometric and single telescope data, providing complete flux recovery. ALMA will cover a spectral wavelength range from 7mm to 0.3 mm or shorter wavelengths, providing astronomy with its first detailed look at the structures which emit millimeter and submillimeter photons, the most abundant photons in the Universe.

The ALMA specifications are described in the ALMA Construction Project Book, which may be found on the Worldwide Web at www.alma.nrao.edu. Table 1. summarizes the sensitivity of ALMA in various modes and at various frequencies.

ALMA's great sensitivity and resolution make it ideal for medium scale deep investigations of the structure of the submillimeter sky.

Existing or other planned surveys are most appropriate for medium to large scale more shallow imaging (e.g. SCUBA, ISO, FIRST, SIRTF, LMT, GBT). The completed surveys cover scales of 0.2 deg^2 or smaller, and cover fluxes $S_{850\mu m} > 1$ mJy. ALMA may cover regions $<.01$ deg^2 to sensitivities nearly

Table 1. Summary of ALMA Sensitivities

Band no.	Frequency Range (GHz)[a]	Continuum (mJy; 60s)	Line (1 km s^{-1}) (mJy; 60s)
1	31.3–45	0.02	5.1
3[b]	84–116	0.027	4.4
4	125–163	0.039	5.1
6[b]	211–275	0.071	7.2
7[b]	275–370	0.120	10
9[b]	602–720	0.849	51
10	787–950	1.26	66

[a] Frequency ranges as given in *Specifications for the ALMA Front End Assembly*, Draft 1.4, August 31, 2000.
[b] These 4 bands are the highest priority bands, the others are the second priority bands.

two orders of magnitude deeper in reasonable integration times. Since ALMA is a high resolution imaging telescope, and can interferometrically filter flux on scales larger than several tens of arcseconds, its confusion limit will be reached at much deeper levels than for the monolithic telescopes thus far employed in submillimeter sky surveys. Hence ALMA can be operated in a mode insensitive to cirrus emission, or fluctuations from the cosmic microwave background, for the purpose of deep sky surveys.

Secondly, ALMA is intrinsically a spectroscopic instrument. Hence, for any image, any emission line falling within the broad ALMA bandpass will be resolved by the 25 km s^{-1} typical resolution of the correlator. This spectroscopic capability, combined with the broad bandpass, will allow ALMA to measure distance as well as spatial distribution of galaxies, when observations at several frequencies are combined to resolve ambiguities in redshift.

2. Methodology

As the basis for the simulation, we employ the local $60\mu m$ luminosity function, determined from IRAS observations (Saunders et al. 1990) as

$\phi_{z=0}(L)=\phi_0(L/L_*)$.

The observed numbers of emitters at $850\mu m$ greatly exceeds what we might expect from this function, hence evolution of galaxies appears to have occurred. Usually, $\phi_{z=0}(L)$ is modified by functions g(z) and f(z) which break up evolution into density and luminosity terms:

$\phi(L,z)=\mathrm{g(z)}\phi_0(L/f(z),0)$.

Blain et al (1999) assumed pure luminosity evolution, in part because pure density evolution cannot simultaneously reproduce the observed number counts and the intensity of the far-infrared background observed by COBE. Several models are described; for expediency we have selected the 'Peak-5' luminosity evolution model for the purpose of our simulations:

$f_{peak}(z) = 2\left[1 + exp(\frac{z}{z_{max}})\right]^{-1}[1+z]^{p+z_{max}/2}$.

The shape of the spectral energy distribution must also be defined; from the discussion in Blain et al. we adopt blackbody shape characterized by a dust temperature of 40 K. A catalog is then generated of the character and number of sources at different values of z, for a given frequency, sensitivity, cosmology and field size.

An image is then generated from this catalog of sources. To illustrate ALMA's capabilities, we have simulated a moderately deep survey over a region similar in size to that surveyed by the Hubble Space Telescope. At the ALMA site, at an elevation 16500 feet on Cerro Chajnantor, Chile near the Bolivian and Argentinian borders, instrumental sensitivity and atmospheric clarity suggest that initial imaging should be performed in the $850\mu m$ window. The array beam size ($1''$in the compact array), pixel size, and expected rms (10 μJy for two hours per pointing) are used to generate an image.

In broadest band mode, the total coverage from edge to edge of the 8 GHz wide upper and lower sidebands is 24 GHz, so the pseudo continuum band should be centered in the atmospheric window, which is not much wider than this. The observations will be taken in spectral line mode but with coarse resolution covering all 8 GHz centered on 339 GHz in the LSB. In the USB, the 4-12 GHz IF centers us at 355 GHz, again with 8 GHz coverage. This results in the total band matched well to the atmospheric window. Only 16 GHz can be processed at a single time, so maximum frequency coverage involves using only one polarization for each sideband. An alternative mode of operation might be to combine both polarizations in one 8 GHz band, and image several times at adjacent frequencies. However, the sensitivity of ALMA is great enough that maximizing the frequency coverage in a single setting provides maximum spectral coverage for ALMA as a 'redshift machine', for serendipitous detection of e.g. CO line emission from distant objects.

For this experiment, we are interested in maximum bandwidth. The minimum frequency resolution per spectral channel is 31.25 MHz, or 27.2 km/s; 90% of the analog bandwidth will be usable for a total spectral coverage of 12,500 km s^{-1}, though non-contiguous.

Since ALMA may be capable of resolution of some of the galaxies, we represent them as featureless disks of a certain size (5kpc was chosen here), and their flux is spread over the appropriate number of pixels. The galaxies are distributed randomly over the field size, randomly oriented. For visual interpretation, the final image is coded according to the redshifts of the galaxies, with a breakpoint at z=1.5. Galaxies at z<1.5 are shown in the left panel of Figure 1; galaxies at z>1.5 are shown in the right panel. There are no galaxies beyond a redshift of z=5 in the Blain et al. (1999) model.

A sizable fraction ($\sim$75%) of the galaxies detectable in our paradigm image would be detectable in CO also. About 16% of the galaxies might have lines which are detectable and actually fall within the passband of the image formed by a 64 x 12m array.

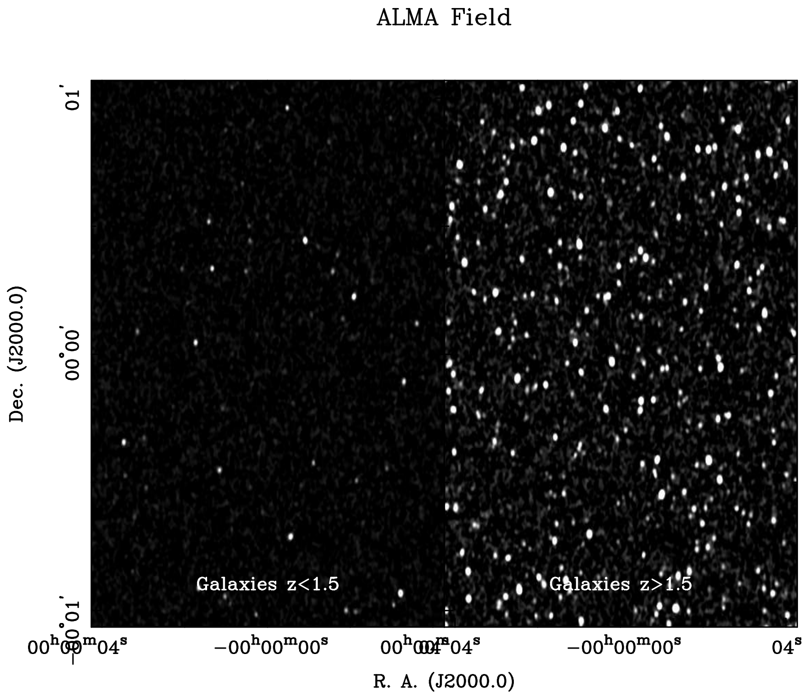

Figure 1. A simulated medium deep field image for ALMA under assumptions described in the text. Each pointing is assumed to use two hours of integration time at 850 μm; several hundred pointings cover a region about the size of the Hubble Deep Field of 6.3 arcmin^2

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3. Conclusions

ALMA will not only detect hundreds of galaxies' continuum emission in this simulation, it will produce redshifts for some hefty percentage of them serendipitously. The optical HDF is dominated by galaxies with z<1.7 though the submillimeter HDF would be expected to have a somewhat different redshift distribution. As is clear from the Figure, under the assumptions outlined here surveys with ALMA will produce images containing large populations of distant galaxies.

References

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