The Atacama Large Millimeter Array Observing the Distant Universe

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Abstract. Observations at millimeter and submillimeter wavelengths will be crucial for understanding galaxy formation and evolution in the early universe. Much of the star formation in the cosmos occurs in galaxies heavily obscured by dust, where optical and ultraviolet energy from young stars and AGNs is absorbed and reemitted at far infrared/submillimeter wavelengths.

When complete around 2012, the Atacama Large Millimeter Array will provide unprecedented capabilities for observing the continuum and spectroscopic properties of objects in the distant universe. Some observational possibilities are reviewed.

1. The millimeter and submillimeter universe

Over the past decade, the importance of observations at millimeter and submillimeter for understanding galaxy formation and evolution in the early universe has become increasingly apparent with the discoveries of a far infrared/submillimeter background and a population of dusty, star forming galaxies at high redshift. Aside from the Cosmic Microwave Background, the extragalactic background radiation is roughly evenly divided in intensity between the far infrared/submillimeter and the near infrared/optical bands (e. g. Blain et al. 1999). Most, if not all, of the submillimeter background can be accounted for by the discrete sources identified in surveys with SCUBA and MAMBO. These high sensitivity, but modest resolution surveys are, however, limited by source confusion. These results suggest a majority of the star formation in the universe occurs in heavily obscured galaxies, where the optical and ultraviolet energy from young stars and AGNs is absorbed by dust and reemitted at far infrared/submillimeter wavelengths.

In the far infrared, the predominant emission mechanism is thermal radiation from optically thin dust. Because this has a very steep spectrum, the reshift of the source spectrum offsets the dimming caused by distance, so the flux at a particular submillimeter wavelength is almost independent of distance for $1 > z > 10$ (e. g. Guiderdoni et al. 1999). A similar, although somewhat weaker, effect applies to thermalized molecular lines in a rotational ladder, i. e., CO. As a result, millimeter and submillimeter surveys have a relative bias toward high redshift sources compared with optical surveys.

2. The ALMA Project

The Atacama Large Millimeter Array (ALMA) project is an international partnership between North America and Europe to construct a new aperture synthesis telescope for millimeter and submillimeter astronomy. When complete around 2012, the ALMA will consist of 64 parabolic antennas, each 12 m diameter with a surface accuracy better than 25 μm. These antennas will be deployed in configurations ranging from 150 m to 14 km in diameter. State of the art, wide bandwidth receivers and an advanced technology correlator will provide unequalled sensitivity for continuum and spectroscopic observation at frequencies between 30 and 900 GHz (Table 1). The ALMA will provide almost an order of magnitude improvement over existing facilities.

Table 1. ALMA Specifications

Antennas	64×12 m
surface	$< 25\,\mu$m rms
pointing	$< 0.6''$
total collecting area	$> 7000\,\mathrm{m}^2$
Configurations	150 m – 14 km
resolution (@ 300 GHz)	$1.4''$–$0.015''$
Receiver bands	10 (4 initial)
frequency	30–950 GHz
wavelength	10–0.3 mm
Receiver noise	3–10 $h\nu/k$
Correlator	16 GHz / 4096 channels
Site	Chilean altiplano (5050 m)

3. Observing Conditions

The ALMA antennas will be deployed on a high (5050 m) plateau southwest of Cerro Chajnantor, Chile, about 40 km east of the village of San Pedro de Atacama and 250 km east of Antofagasta. This site was chosen after an extensive site characterization program. Measurements since 1995 have demonstrated Chajnantor is among the best sites known. Measurements of the 183 GHz line (Delgado et al. 1999) indicate the median precipitable water vapor (PWV) for all of 2000 was about 1.8 mm. During the winter, May to August, the median PWV was 0.6 mm. Under typical conditions, the PWV is 2–4 times lower at night than during the day. Continuum (Radford 2002) and spectroscopic measurements (Matsushita et al. 1999, Paine et al. 2000) of the atmospheric transmission indicate good conditions for submillimeter (675 or 875 GHz) observations occur more than one third of the time overall and about half of the winter time. At Chajnantor, super-terahertz (1035, 1350, or 1500 GHz) observations should be possible about 11% of the time overall and 15% of the winter time (Matsushita et al. 1999). Even better conditions prevail on nearby mountain peaks (Blundell et al. 2002).

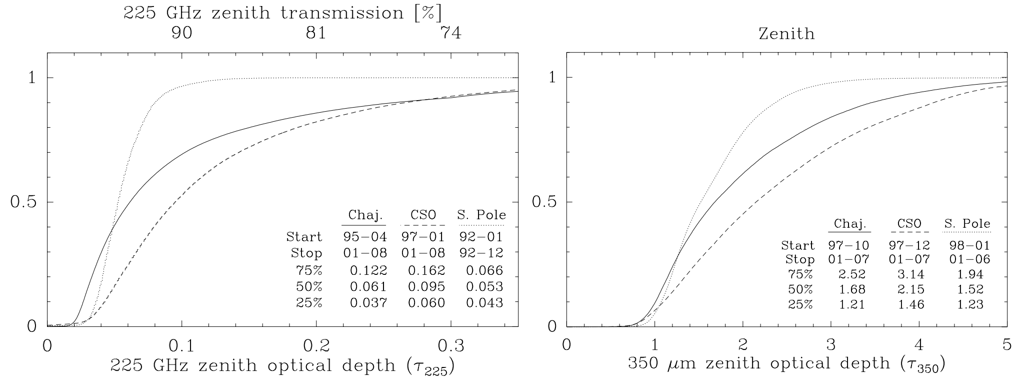

Figure 1. Cumulative distributions of the 225 GHz (τ_{225}) and 350 μm (τ_{350}) zenith optical depths measured at Chajnantor, Mauna Kea, and the South Pole (after Radford & Chamberlin 2000 and Radford 2002).

4. Continuum observations

ALMA will be well suited both for follow up observations of submillimeter sources identified by other, possibly confusion limited surveys and for deep surveys to discover new objects. ALMA's sensitivity and resolution will permit detection and unambiguous identification of infrared luminous galaxies at any redshift since reionization. Even normal (L^*) galaxies will be detectable at large redshifts ($z \approx$ 2–3). Compared with optical surveys, an ALMA survey will preferentially detect distant ($z > 1.5$) galaxies. Observations in several ALMA bands will determine the galaxies' luminosities, spectra, and approximate redshifts (e. g. Wiklind 2003).

5. Spectroscopy

ALMA will observe CO, HCN, and other molecular species to determine the physical conditions of the interstellar medium in distant galaxies. Because of the $(1 + z)$ compression of the line spacing and ALMA's wide bandwidth receivers, one or more CO lines will be detected in a significant fraction of the galaxies seen in a deep ALMA survey, allowing precise redshift determination. The strong [CII] 158 μm fine stucture line will be redshifted into the ALMA bands for sources at $z > 1.5$.

Observations of molecular absorption line systems against background sources provide a wealth of information about interstellar gas in distant galaxies (e. g. Wiklind & Combes 1998). ALMA's sensitivity will permit observations of much fainter background sources, greatly expanding the sample of absorption line systems.

6. Lensing

A large fraction of high redshift sources are gravitationally lensed by intervening galaxies or clusters along the line of sight. ALMA's deep, high resolution images will permit detailed studies of both the lens potentials and the background galaxies. In the case of strong lenses, the lens magnification will augment ALMA's sensitivity to allow studies of even fainter, more distant background galaxies.

Acknowledgments. This brief survey illustrates only a few of the observations possible with ALMA. I thank the many colleagues who have participated in defining ALMA's scientific goals and capabilities.

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