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THE LARGE MILLIMETER ARRAY

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ABSTRACT In Japan, there is a plan for Large Millimeter Array proposed by Nobeyama Radio Observatory. The proposed array may consist of 50 10-m antennas distributed in a 2 - 3 km area at very high altitude. In this paper, scientific directions, planned system, and site survey for the LMA are reported.

INTRODUCTION

Millimeter wave interferometry has improved our understanding of fine structures of molecular line emission and continuum emission in various astronomical objects. The operating arrays have been very productive and are currently being expanded in their capabilities. However, the limitation in resolution and sensitivity of the existing arrays is preventing observations from resolving protoplanetary disks and detecting high-z galaxies.

As a natural extension of the existing millimeter arrays, the Large Millimeter Array (LMA) is proposed in Japan. This project was initiated by an idea to realize a large array by adding 25 more antennas to the Nobeyama Millimeter Array. As the Nobeyama site, however, is seriously limited by atmospheric performance, we have decided to look for a very good site outside Japan. The array concept is extended to realize sub-arcsec resolution imaging at very high frequencies.

The LMA may consist of 50 10-m antennas and will be covering observing frequencies from 35 to 500 GHz (possibly 650 and 800 GHz). Scientific directions, the planned system, and the site survey for the LMA are reported.

SCIENCE WITH THE LARGE MILLIMETER ARRAY

High sensitivity and sub-arcsecond imaging capability will produce a lot of remarkable scientific results. In particular observations of protoplanetary disks and detections of high-z galaxies would be one of the most exciting scientific targets.

Protoplanetary Disks

Recently, rotating protoplanetary gas disks around young stars was revealed with millimeter interferometers (e.g. Kawabe et al. 1992). However, it is impossible to resolve the structure sufficiently with 2-3$''$ resolution of the existing

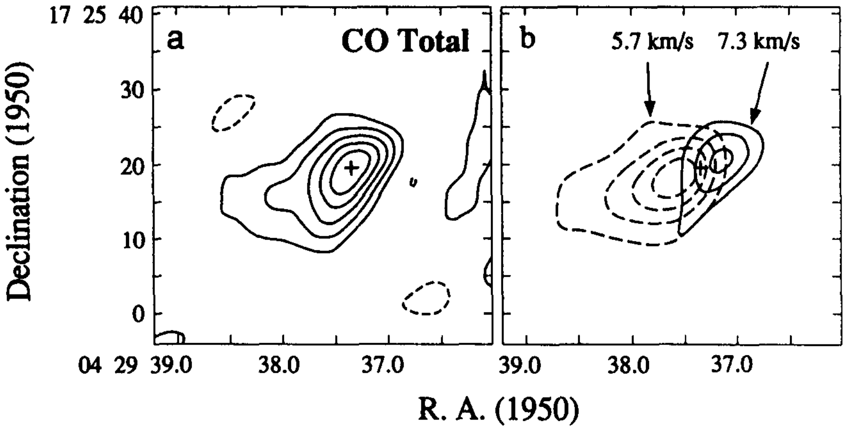

Figure 1 CO(1-0) map of a T-Tauri star GG-Tau, obtained with Nobeyama Millimeter Array (Kawabe et al. 1993). The CO map revealed a rotating protoplanetary (or circumbinary) gas disk around GG-Tau. The radius of disk is found to 500 AU.

arrays. It is also difficult to observe many samples for studying evolution of the protoplanetary disks because of limitation of number of antennas and sensitivities of the arrays. Sub-arcsecond imaging is essencial in order to resolve protoplanetary disks in nearby star forming regions such as the Taurus region where 0.1″ at a distance of 140 AU corresponds to 14 AU, just a scale of the planet forming region in our solar system. Quick imaging is also important to obtain more samples for statistical investigations of the planet formation.

Observations of both dust emission and higher excitation molecular lines (sampling inner region) with a high resolution would be important to analyze the formation of planetary systems. Efficient observations of dust emission will be possible at frequencies, 230 and 345 GHz (possibly 400 GHz), because dust emissiion gets stronger at higher frequencies.

High-z Galaxies

The formation and evolution of galaxies and QSOs, in terms of star formation and AGN activities, are also very important in astronomy. Recent millimeter-wave observations of CO from the protogalaxy candidate IRAS F10214+4724 with single dishes and interferometers indicates that the huge amount of molecular gas is associated with the high-z galaxy with an extremely high infrared luminosity, $L_{IR} = 0.8 \times 10^{14}\ h^{-2}\ L_{\odot}$(Brown and Vanden Bout 1990, Kawabe et al., 1992). Fig. 2 shows a CO(3-2) map of IRAS F10214+4724

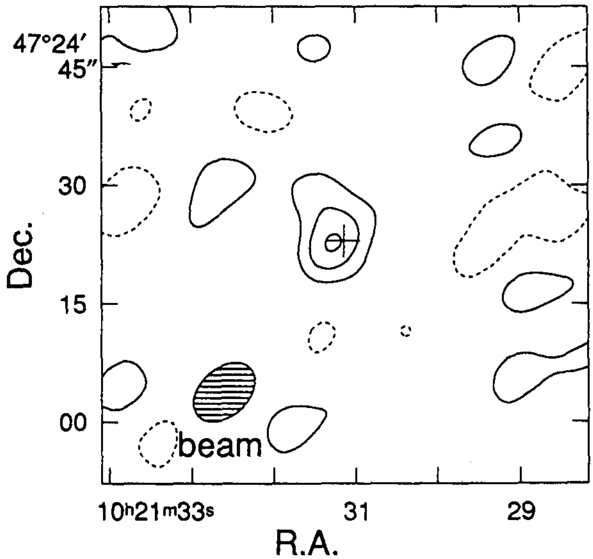

Figure 2 The NMA CO(3-2) map of a protogalaxy candidate IRAS F10214+4724 at z = 2.286 (Kawabe et al. 1992; Rowan Robinson et al. 1991).

observed with the NMA (Kawabe et al., 1992; Sakamoto et al. 1992). In these kinds of observations of distant objects, higher sensitivity and sub-arcsecond resolution are also desired (there are not so many sources with $L_{IR}=10^{14}\ L_{\odot}$ and 1″ corresponds to about 4 kpc at high-z). Sufficient sensitivity is required to reach a distant IR bright galaxies (like Arp220, with $10^{12}\ L_{\odot}$) up to z=5.

In addition to the observations of the known high-z galaxies and QSOs, LMA as a quick imaging instrument would be a powerful tool to search for new high-z sources. It is estimated that about a few tens of high-z galaxies will be newly detected by a snap-shot survey of about 10^4 fields of view (covering about 1°× 1°) with LMA continuum observations at a frequency of 230 or 345 GHz. Searching for high-z "proto-quasars" might be possible by the observations of highly redshifted emission of a strong [CII] 128 μm line (Loeb 1993).

DESCRIPTION OF THE PLANNED SYSTEM

Scientific requirements described in previous section define the following capabilities of the LMA,

1. Wide frequency coverage at millimeter wavelengths (40 - 500 GHz);
2. Sub-arcsecond imaging at λ 1mm;
3. Highest sensitivity at millimter wavelengths;
4. Very quick imaging with high dynamic range.

Table 1 Summary of Instrumental Parameters

Array		
	Number of Antennas	50
	Total Collecting Area	3927 m^2
	Baselines	20 m - 2 km
	Maximum Angular Resolution	$0.''1$ ($\lambda = 1$ mm)
Antennas		
	Diameter	10 m
	Surface Accuracy	< 20 μm rms
Frequencies		
		35 - 50 GHz
		80 - 115 GHz
		130 - 170 GHz
		200 - 300 GHz
		330 - 350 GHz
		450 - 495 GHz
Correlators	FX-type	
	Bandwidth	4 GHz
	Frequency Channel	> 10000 ch
	Max. Freq. Resolution	40 kHz (0.1 km s^{-1} at 115 GHz)

To achieve a maximum angular resolution of $0.1''$, the array dimension must be more than 1-km. In a preliminary design of the array, fifty 10-m antennas are considered to achieve a total collecting area of 4000 m^2 corresponding to that of a single dish of 71-m diameter. With this collecting area, about 100 μJy (5σ) sensitivity will be acheived. Fig. 3 shows an example of array configuration. In this design, the array consists of two sub-arrays, one is fixed and latter is variable. This configuration has good instantaneous (u, v) coverages, which provide high quality images in short interval of good atmospheric condition. Such a capability of rapid imaging is very important, because phase fluctuation due to atmospheric turbulence is very serious for high resolution imaging at millimeter wavelengths.

The antennas must be designed for efficient operation at frequencies as high as 500 GHz, which requires a surface accuracy less than 20 μm rms and a pointing accuracy of $\sim 1''$. Receivers will be located at fixed positions in the lower cabin and will be selected by a rotating mirror. Dual-polarization receivers in the atmospheric windows between 40 GHz and 500 GHz are planned for each LMA antenna. In each band a large tuning range is desirable, so that one can observe anywhere within the entire frequency band. These receivers will have a bandwidth of >4-GHz. Phase stabilized optical fibers will be used for transmission of reference signals for phase-locking and IF return signal.

Wide band FX type correlator system will be used which can offer flexible operations. For spectral-line observations, it may function as several separate spectrometers, all of which may be tuned to different central frequencies from the same or different receivers

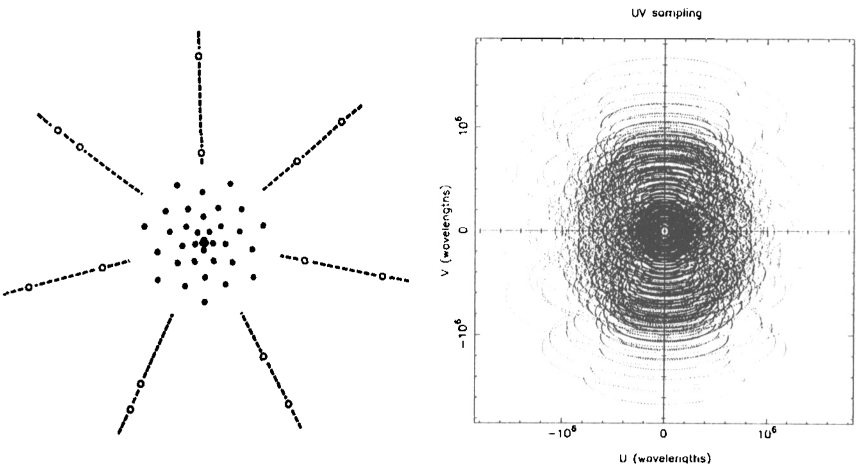

Figure 3 (a) An example of array configuraton. (b) (u,v) coverage.

The quick imaging property of LMA allows us to collect data sets with a good uv-coverage in a good radio seeing condition, so that we can obtain a high quality and high resolution image using an ensemble of good snap-shots.

SITE SURVEY

The Potential Sites for the LMA

The criteria for the potential LMA site are 1)good atmospheric transparency at millimeter and submillimeter wavelenghts, 2)good radio seeing to achieve sub-arcsec resolution, 3)low wind velocity for a good pointing accuracy, 4)flat and wide ($\sim$ 3 km $\times$ 3 km) area to locate the array, 5)accessibility to the site, 6)Infrastructure, etc. Under these criteria, the potential LMA site should be a very dry site at very high altitude.

Mauna Kea, Hawaii and the Atacama desert in northern Chile are considered as the potential sites for the LMA in northern and southern hemisphere, respectively. As site testing has already been conducted on Mauna Kea by other groups, we decided to focus our site testing activities in northern Chile. The Atacama desert is one of the most arid deserts on Earth and the mean annual precipitation is less than 10 mm, indicating the area is expected to be a very good site for astronomical observatories(Grenon, 1990). There is a very flat area at high altitude suitable for locating the LMA. The ESO VLT is under construction on Cerro Paranal which is one of the very good site in northern Chile.

In 1992, we have visited about twenty of possible sites in northern Chile (Fig. 4) under a collaboration with SEST/ESO group and University of Chile. These sites are distributed 22.5° to 25.5° in latitude and 2500 m to 4800 m in

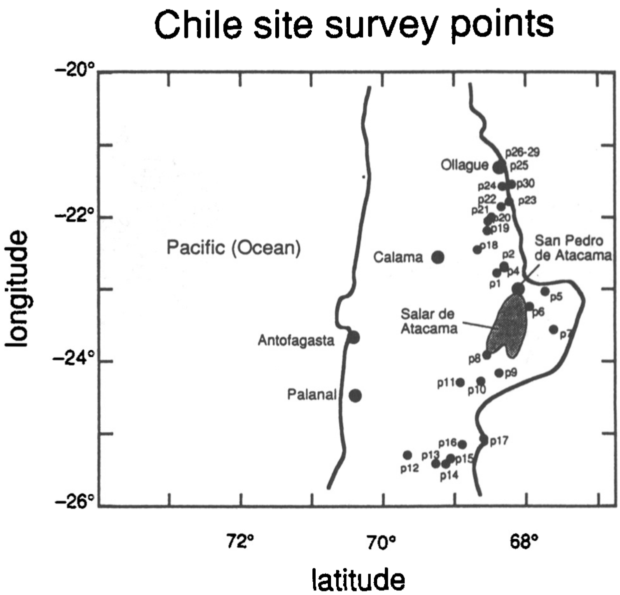

Figure 4 Site survery points in northern Chile.

altitude. Fig. 5 shows the temperature and the water vapor pressure measured in the second visit in 1992 (September 20 - October 3). Although the data are very limited, variation of the temperature and the water vapor pressure with altitude is clearly seen in the figures. The water vapor pressure is very low at a very high site inspite that these data were taken in daytime.

We are planning to start a more extensive site testing in 1993 with a set of small interferometer to measure atmospheric phase fluctuations, 220 GHz radiometer and weather station at one of possible LMA sites.

Site Testing with a Radio Seeing Monitor

To achieve sub-arcsec resolution at millimeter and submillimeter wavelengths site selection is essential. The principal limitation in achieving very high angular resolution is atmospheric phase fluctuations. So far, site surveys has been based on the opacity measurements in which atmospheric phase stability has been evaluated indirectly. Recently, it is proved to be very useful to asses the site performance with direct measurements of the atmospheric phase fluctuations by using a small interferometer to receive a signal from a geostationary satellite (Ishiguro et al. 1990).

The first interferometer for such a purpose was built at Nobeyama and has been used to study spatial and temporal structure of atmospheric phase fluctuations. This is a linear array of five 1.8-m antennas with a maximum baseline of 253 m. The antennas are pointed to a Japanese communications

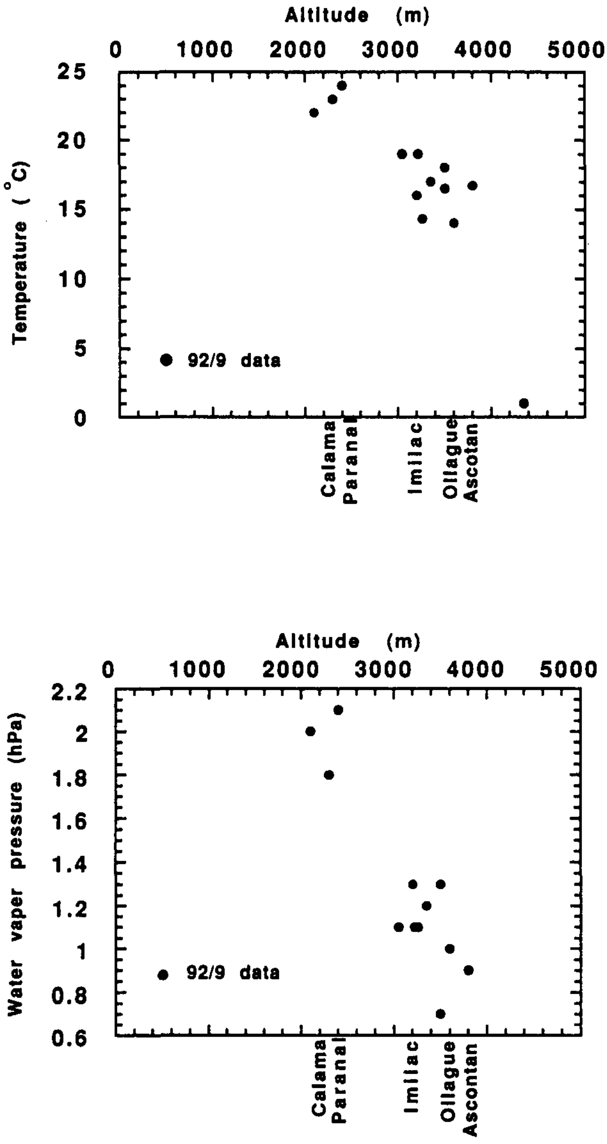

Figure 5 Meteorological data at some survey points.

satellite to measure the signal phases at 19.45 GHz at ten different interferometer baselines. The advantages is that it is possible to monitor the phase fluctuations continuously at a constant elevation angle. This kind of interferometer is called as Radio Seeing Monitor(RSM).

A new RSM is under development at Nobeyama to be used for the LMA site survey. This instrument consists of a pair of 0.6 m antennas separated about 100 m which receive a beacon signal at 11.198 GHz or 11.452 GHz from an INTELSAT satellite. The antenna is a Radial Line Slot Antenna (RLSA) which has high aperture efficiency. A small antenna is adopted because it is very compact and easy to transport. The signal received with each antenna is amplified by a low-noise HEMT amplifier and converted to 1.198 GHz and transmitted by a coaxial cable to the central IF receiver. The reference signal at 62.5 MHz to phase-lock the 10 GHz local oscillator and DC power for the front end are also provided through the same coaxial cable. The phase difference between the signals received with two RLSA antennas is measured by a HP 8508 vector voltmeter and recorded by a small computer system.

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