The Large Millimeter and Submillimeter Array

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***Abstract*:The Large Millimeter and Submillimeter Array (LMSA) is a top-priority project of large ground-based astronomical facilities of Japan, and will consist of fifty high-precision 10 m antennas with baselines up to 10 km. Equipped with sensitive receivers, wideband correlators, and phase correction techniques, the LMSA will achieve a 0.01 arcsecond resolution at millimeter and submillimeter wavelengths and a very high sensitivity corresponding to a 70 m dish. LMSA is planned to be located on a high, dry, and flat site in the northern Chile, and to be operated from around the year of 2008. Its main scientific targets include planetary system formation and galaxy formation/evolution. A big advance in the researches of cosmology, active galactic nuclei, star formation, interstellar matter, and planetary science is also expected. Discussion about international collaboration toward a world array has been started.**

***Index terms*:Submillimeter-wave astronomy, interferometer**

I. INTRODUCTION

A. *Outline of the Project*

The Large Millimeter and Submillimeter Array (LMSA) [1, 2] is a top-priority project of large ground-based astronomical facilities of Japan, which will provide a 0.01” (1” = 1/3600 degree) resolution at millimeter and submillimeter wavelengths and a very high sensitivity corresponding to a 70 m dish. The LMSA will consist of fifty high-precision 10 m antennas equipped with sensitive receivers covering entire atmospheric windows in short-millimeter and submillimeter wavelengths. The LMSA is planned to be located on a high, dry, and flat site in the northern Chile, and to be fully operational from around the year of 2008.

B. *Scientific Impact of Submillimeter-wave Astronomy*

Recent progresses in researches on the formation and evolution of galaxies as well as those on the formation of stars and planets have been provided by high-resolution observations in millimeter wavelengths achieved with existing interferometers such as the Nobeyama Millimeter Array. Epoch-making observations in this field include a discovery of a forming galaxy [3] and a discovery of a protoplanetary disk around a young star [4]. Because of the limited performance (e.g., sensitivity and angular resolution) of the existing millimeter-wave interferometers, however, a new breakthrough facility is needed to make further jumps in these researches.

Fig. 1 Artist痴 impression of the Large Millimeter and Submillimeter Array (LMSA).

Astronomical observations in submillimeter wavelengths provide breakthrough on observational astronomy, not only because observations through submillimeter-wave windows are new but because (1) thermal emission from cold (~10K) interstellar medium peaks in submillimeter wavelengths, (2) submillimeter waves are transparent to an obscuration by interstellar dust which makes forming stars and galaxies invisible in optical and infrared wavelengths, (3) higher angular resolution is achieved by observations in shorter wavelength, (4) there are abundant spectral lines in millimeter and submillimeter wavelengths from interstellar molecules that turn into stars and planets.

Main scientific targets of the LMSA include planetary system formation and galaxy formation/evolution. The maximum angular resolution of 0.01” is ~10 times finer than that achieved by the world痴 largest optical/infrared telescopes, and corresponds to 1.4 AU (Astronomical Unit) at the distance of the Taurus dark cloud, 85 AU at the Galactic center, 530 AU at the Large Magellanic Cloud, 0.9 pc at the Virgo cluster of galaxy. The synthesized beamsize is always smaller than ~100 pc even in the deepest Universe. Mountains of only 40 km diameter can be resolved even at the distance of Io, the Galilean satellite of Jupiter. A big advance in the researches of cosmology, active galactic nuclei, star formation, interstellar matter, and planetary science is also expected.

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In the following sections of this paper we will present brief introduction of the instrumentation and technical challenges for the LMSA, as well as the characteristics of the site and a movement toward international collaboration. Detailed description on the technical achievement related with this project will be given in a separate paper by Kawabe et al. Further information of this project is available through the web at http://www.nro.nao.ac.jp/~lmsa/.

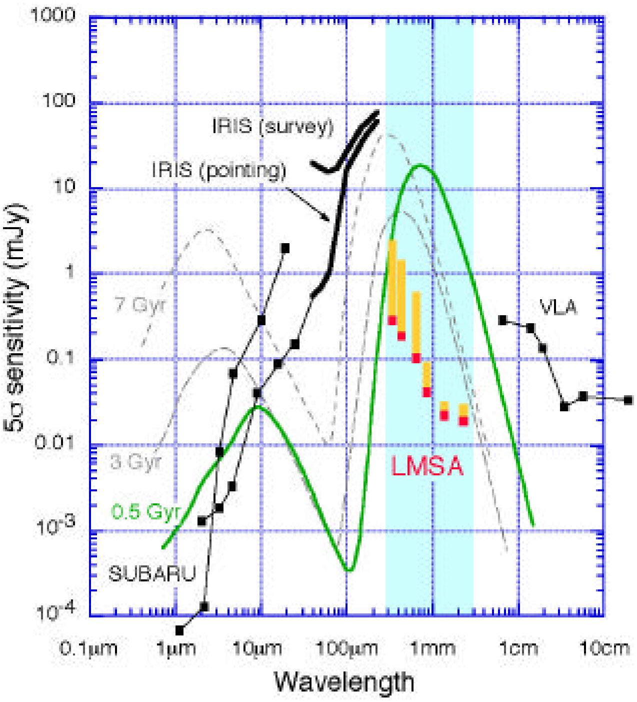

Fig. 2 Sensitivities of LMSA and other major astronomical instruments overlaid on theoretical spectral energy distributions of a medium-sized (10^{11} $M_{\odot}$) young elliptical galaxy in its different stages of evolution (0.5, 3, and 7 Gyr after its formation) [5]. Assumed integration time is 8 hr for LMSA and VLA while it is 1 hr for Subaru. Note that, because of the positive effect of redshift, younger galaxies in deep universe are brighter in millimeter and submillimeter wavelengths while in optical and infrared wavelengths they are dimmer and thus are easily contaminated by less massive evolved galaxies in nearby universe.

II. Outline of the System and Technical Development

A. *Summary of the Proposed System Specifications*

The proposed system specifications of the LMSA are summarized in Table 1.

Table 1 Proposed system specifications of the LMSA

Array		
	Number of antennas	50
	Total correcting area	~4000 m^2
	Baseline (max)	10 km
	Angular resolution (max)	0.01”
Antennas		
	Diameter	~10 m
	Surface error (rms)	<17 µm
	Pointing error (rms)	<0.7”
Receiver		
	Frequency bands	80– 140 GHz
		130– 200 GHz
		200– 310 GHz
		330– 420 GHz
		390– 500 GHz
		630– 710 GHz
		800– 890 GHz
Correlator		
	Type	FX or XF
	Cross correlations (/band/pol.)	1225
	Bandwidth (max)	>4 GHz
	Frequency channels (/baseline)	>10000
	Frequency resolution (max)	40 kHz

B. *High Precision Antenna*

Design of the element antennas is one of the key items in the research and development phase. It is not only because the antennas define basic specifications of the array, but also because the antennas will cost about half of the total cost and, once constructed, they are hardly replaced.

Specifications of the LMSA element antenna shown in Table 2 were determined as follow. The maximum surface error was set so that it is ~1/20 of the shortest wavelength (340 µm). The maximum pointing error was determined not to exceed 10% of the 7” field -of-view of the element antenna at the shortest wavelength to ensure the mosaicking capability. Maximum slue rate was set to enable fast switching for phase calibration. Radomes or astrodomes are not suitable in terms of both transportability and close packing.

Table 2 Specifications of the LMSA antenna

Diameter	~10 m
Frequency range	80– 890 GHz
Surface error (rms)	<17 µm
Pointing error (rms)	<0.7” (Night, wind velocity <7m s^{-1})
Phase stability (rms)	<20 µm
Slue rate	>2 deg s^{-1}
Receiver cabin	>2 m x 2 m x 2 m
Transportability	all
Radome/astrodome	no

As for the diameter of the element antenna, a trade-off study is needed to fix the final design. Larger antenna gains per-cost sensitivity while it loses field-of-view and consequently introduces a drawback to pointing accuracy.

A high-precision 10 m antenna as a prototype of the LMSA element antenna is under development and will be delivered to Nobeyama during the winter season of 1999–2000.

C. Submillimeter-Wave Receivers

Receivers for the six atmospheric windows from 80 to 890 GHz are planned for each antenna. Dual polarization receivers will be included for the 345 GHz and 650 GHz bands. Superconductor-Insulator-Superconductor (SIS)-type mixers will be adopted for most of these bands. Mixer noise temperature required for the LMSA receivers is just a few times the quantum limit at each frequency band.

Development of sensitive mixers is among the largest technical challenges, and in-house development of millimeter- and submillimeter-wave junctions are currently ongoing. Recently a novel type of SIS junction called 泥istributed Junctions” has been developed at the Nobeyama Radio Observatory. This new type of mixer involves a number of SIS junctions distributed along a thin-film transmission line. Its excellent performance has been experimentally demonstrated both in the laboratory and on the telescope.

Mass production of state-of-the-art mixers is also to be considered, because a total of 400 mixers will be fabricated and installed on the array. Some experience on this issue has already been obtained on the course of the development of the 25-element focal plane array receiver installed on the Nobeyama 45 m telescope.

D. Wideband Correlators

Two different types of correlators – FX and XF – are considered as a spectro-correlator for the LMSA. The XF-type correlator makes cross-correlation (X) before Fourier transform (F), and is more simple and flexible to select either wide-band observations or high spectral-resolution ones. On the other hand, the FX-type is able to handle large number of correlations and simultaneously covers wide band with very high spectral resolution.

As the number of cross correlation increases roughly in proportion to the number of elements, significant jumps in integration technique are needed from the present six element array (30 correlations) to the proposed fifty element array (1225 correlations).

E. Collaboration on Technical Development with Universities, National Laboratories, and Industries

Technical development for the LMSA has been achieved also in universities via the activities of working groups and under the frameworks of the LMSA collaborative development fund (~4 themes, ~10M JPY/year in total) of the Nobeyama Radio Observatory, and the NAO collaborative development fund of the National Astronomical Observatory of Japan. Accepted proposals so far are mostly on receiver development such as development of NbN SIS terahertz mixers, an SIS photon detector array, a 492 GHz SIS receiver, a 492 GHz radiometer for site testing, 345 GHz single-sideband SIS mixers, 230 GHz harmonic mixers, and a polarimeter for millimeter-wave astronomy, and also evaluation of the stability of 4 K cryocoolers.

III. THE SITE

In 1990, we started site survey for the LMSA. The criteria for the site are: (1) high atmospheric transparency at submillimeter wavelengths, (2) good radio seeing, (3) flat and wide (>3x3 km) area for the large array, (4) low wind velocity for accurate pointing of the antenna, (5) easy accessibility, (6) political state of host country, and so on. Those surveyed include high mountain sites, e.g., Mauna Kea (4200 m, Hawaii, USA), northern Chile such as Pampa la Bola (4800 m, Chile) and Rio Frio (4100 m, Chile), Hanle (4500 m, India), and Delingha (3200 m, Qinghai, China).

Fig. 3 Locations of candidate LMSA sites in northern Chile. Pampa la Bola is only a few kilometers apart from the paved international highway from Chile to Argentina.

After basic examination of meteorological data, we started in 1992 our first site survey activity for the LMSA in northern Chile (Figure 3) in collaborations with the European Southern Observatory and the University of Chile. We visited about twenty of possible sites from – 22.5 to – 25.5 degree in latitude and from 2500 to 5000 m in altitude.

In July 1995, we installed at Rio Frio a 220 GHz tipping radiometer and an 11 GHz radio seeing monitor, which is a small interferometer receiving a geostationary satellite signal. The same set of equipments was installed in 1996 also at Pampa la Bola (Figure 4). By comparing the atmospheric conditions (e.g. the atmospheric transparency and the radio seeing) and also the accessibility of these sites, we decided the Pampa la Bola-Chajnantor region as the candidate site of LMSA.

Fig. 4 Site testing instruments and containers at the 4800 m site of Pampa la Bola, Region II, Chile. Two containers equipped with solar panels and one of the element antennas of the radio seeing monitor can be seen in the background. Three weather stations under cross calibration are seen in the foreground.

Atmospheric transmission from 150 GHz to 1.6 THz was measured at Pampa la Bola in June 1998 with a Fourier-transform spectrometer [6, 7]. The best atmospheric transmission spectrum shown in Figure 5 demonstrates that the peak transmission in the 650 and 850 GHz windows exceeded 60%. Supra-terahertz windows around 1.03, 1.35, and 1.50 THz were also identified.

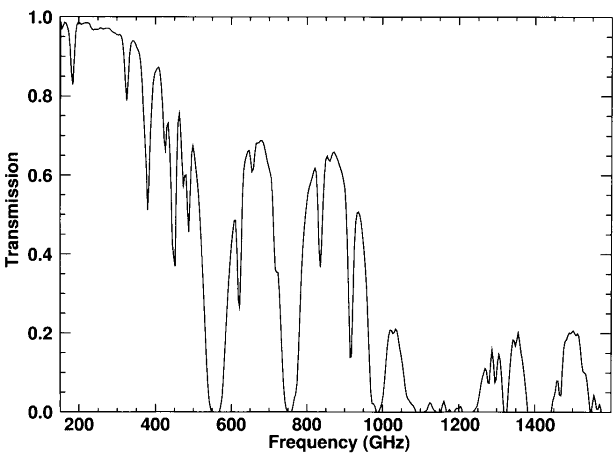

Fig. 5 Atmospheric transmission from 150 GHz to 1.6 THz measured with a Fourier-transform spectrometer in June 1998 (southern winter) at Pampa la Bola, Chile [7].

IV. International Collaboration toward the World Array

There is an international consensus on the scientific importance of a large array in millimeter and submillimeter wavelengths, and projects similar to the LMSA have been planned also in the United States and in Europe. The National Radio Astronomy Observatory (NRAO) of the United States proposed the Millimeter Array (MMA) project [8], whereas the European Southern Observatory (ESO) proposed the Large Southern Array (LSA) project [9]. The original designs of the MMA and the LSA were forty 8 m antennas and fifty 15 m antennas, respectively, both operating in millimeter wavelength. The MMA and LSA projects were later merged into one single project called 鄭tacama Large Millimeter Array (ALMA)," which consists of sixty -four 12 m antennas.

Since both LMSA and ALMA projects are planned to be constructed in the Pampa la Bola-Chajnantor area, a breakthrough is expected by combining these arrays into a more capable array. Design and development activities in these three parties are coordinated toward a world array.

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