Japanese Participation in ALMA: A Proposal

National Astronomical Observatory of Japan

August 16, 2002

Summary

For discussion in the Expanded ALMA Coordination Committee (EACC), the National Astronomical Observatory of Japan (NAOJ) proposes a Japanese participation plan in which NAOJ brings the following items to ALMA:

1. The Atacama Compact Array (ACA) system
2. New receiver bands
3. The Second Generation Correlator (2GC)
4. Contribution to infrastructure and operation

This plan is based on the trilateral ALMA that emerged from the joint effort made most intensively in 2001 by the three partners. The items 1-3 are among the items for the trilateral ALMA recommended by the ALMA Science Advisory Committee (ASAC) in October 2001. NAOJ is preparing the Japanese construction budget request to realize the trilateral ALMA. In particular, it will make ALMA a really powerful instrument for submillimeter-wave astronomy, whose great advancement is foreseen in the first quarter of this century.

NAOJ proposes here the steps to be taken toward the official participation of Japan. In order to realize the trilateral ALMA, it is crucial to revive and keep good cooperation between the ALMA bilateral project and Japan, and it is proposed as an interim framework to continue EACC function, Japanese participation in ASAC, ALG activities, and close communication in the DH/TL level.

1. Introduction

Looking back the history, we see three roots of the ALMA project, i.e., the Millimeter Array project (MMA) in the National Radio Astronomy Observatory of the United States, the Large Millimeter and Submillimeter Array project (LMSA) in Japan, and the Large Southern Array project (LSA) in the European Southern Observatory (ESO). After nearly two decades of intense effort in the three regions, they have evolved into a project to build and operate a single instrument ALMA that is unique in the world.

At its meeting in April 2001 in Tokyo, EACC recognized the advantage of combining the three projects into a single global one, noted the strong ASAC support for a trilateral ALMA Project that leads to a significant enhancement in the science capability, and resolved to work towards the earliest possible final definition of the trilateral ALMA. In accordance with this resolution, the Expanded ALMA Executive Committee (EAEC) and ASAC worked to define the “trilateral ALMA” with its possible work breakdown. With the approval of the project in the United States and in ESO, the project is entering the construction phase with the two official partners, who are building the “baseline” part of the trilateral project.

This proposal presents a possible path for the participation of Japan to the construction as the third major partner, for discussion in EACC and related committees.

2. Guiding Principles

The NAOJ proposes the Japanese participation plan under the following guiding principles.

Realization of the “trilateral ALMA”

As a result of Japanese participation, we try to realize as much as possible the functions of the “trilateral ALMA” that emerged from the joint effort made most intensively in 2001 by the three partners. NAOJ is preparing a budget request to make it possible (see Section 3).

Optimization for science

We try to optimize the Japanese contribution for science within the available resources referring to the ASAC recommendations and discussions within Japanese scientific community that has a strong interest in submillimeter-wave astronomy. We note that the scientific power of ALMA should be valued not only at its start of operation in 2011 but also over the lifetime of the instrument.

Participation as the third major partner

We consider a framework in which Japan can contribute a significant fraction to the construction as the third major partner of ALMA. Japan will contribute also to the infrastructure and operation costs. Japan should obtain intellectual and economic benefit from ALMA in all phases in proportion to the value of their contribution, as the other partners do.

Clear interface with the "baseline" project

We try to keep the interface between the Japanese and bilateral parts of the trilateral ALMA project clean and simple, so that we can avoid unnecessary overhead cost and delay in the project.

3. Japanese Contribution Plan

Overview

Guided by the principles in Section 2 and based on discussions within the Japanese scientific community, NAOJ proposes to bring the four items to ALMA:

1. The Atacama Compact Array (ACA) system

A system of twelve 7-m antennas and four dedicated 12-m antennas all equipped with receiver frontend and backend systems.

2. New receiver bands

    Receiver cartridges for Band 10, Band 8, and Band 4.

3. The Second Generation Correlator (2GC)

    A correlator for 64-element array and ACA with 8k – 64k spectral channels per baseline.

4. Contribution to infrastructure and operation

    Sharing an appropriate fraction of infrastructure and operation costs.

NAOJ is preparing a request for the Japanese ALMA construction budget that starts in FY2004. The budget to be requested can accommodate the above four items (except for the operation cost to be requested separately).

The above items altogether enhance the performance of ALMA greatly, and provide the science community in the world with new opportunities. In particular, these items will make ALMA a really powerful instrument in submillimeter-wave astronomy, whose great advancement is foreseen in the first quarter of this century. With this enhancement, ALMA will play an even more important role in answering key questions in astronomy such as origins of galaxies, planetary systems and life. ASAC has given the scientific justification of the items 1-3 in its recommendation on October 15, 2001. It is a result of active discussion among scientists from North America, Europe, Japan, and Chile. Japanese scientists joined as official members and contributed significantly to the report.

ALMA-J team and collaborating researchers in universities in Japan have been making active development of the key technologies related to items 1-3. It is technically feasible for Japan to contribute them.

The individual items are explained in some detail in the following.

The ACA System

Build a system of twelve 7-meter antennas and four high-performance 12-meter antennas. They are equipped with all the required frontends with the baseline receiver cartridges and the IF/backend systems. The number and diameter of the 7-m antennas are based on the simulation work conducted by ASAC, which leaves a room for fine-tuning. The four 12-meter antennas are equipped with the nutating subreflectors, and will be dedicated to accurate single-dish measurements and calibration of the 7-meter antenna array. The number of the 12-m antennas is based on the requirements for the speed of single-dish data collection and the sensitivity in calibration of the smaller antennas.

The ACA system recovers the spatially extended components of the objects and significantly enhance the imaging and photometric capability of ALMA. The ACA is expected to play a particularly important role for projects at high frequencies, where the objects will in general be larger than the primary beam. Numerical simulations show that in some cases the images without ACA will miss key information leading to an inaccurate interpretation of the data.

Development of accurate antennas is the key to this system. NAOJ has developed and accumulated various technologies related to precision antennas. NAOJ is currently building a 12-m prototype antenna according to the ALMA specification. It will be delivered in 2003 April at the antenna evaluation facility at Socorro, and its performance will be evaluated as a joint task of the ALMA Antenna Evaluation Group (AEG). This prototype will be the base of our four 12-m antennas, and the AEG activity will ensure the feasibility of the Japanese contribution in the antenna area.

Receiver Frontends

Fabricate and install frontend cartridges of three bands to the 64 antennas in the baseline ALMA and the 16 ACA system antennas. For the receiver bands to add, we propose Band 10 with the highest priority and Bands 8 and 4 with the second priority. The number of receiver bands and the number of antennas with the new band cartridges installed are subject to the funding level. Further discussion including the possibility of the other receiver bands might be required.

The new receiver bands will bring new observing windows to ALMA particularly at submillimeter wavelengths. These frequency bands were rated as “Top priority” (Band 10) and “High priority” (Band 8 and Band 4) in the ASAC recommendation. Band 1 was ranked in between the two. Noting that the absolute ranking for the four bands was close, NAOJ propose here the three bands with its priority stated above based on the accumulated development efforts (see below) and the community’s interests in Japan.

Band 10 (767 – 950 GHz) is the highest frequency observing band of ALMA, thus providing the highest angular resolution for a given configuration. It offers unique science opportunities such as observations of the excited [CI] fine structure line, red-shifted [CII] emission, and high excitation lines of fundamental molecules. It will provide continuum flux density information at the highest frequency of ALMA, which will be important for accurate determination of the spectral energy distribution of objects like protostellar cores, protoplanetary disks, protogalaxies and active galactic nuclei.

Band 8 (385 – 500 GHz) is a unique band among the ALMA frequency bands that receives the fundamental [CI] fine-structure line in our own and nearby galaxies. It also provides opportunities to observe the [CII] fine-structure line at an interesting redshifted range of z = 2.7 – 3.8, HDO fundamental transition in solar system objects, and CO J = 4 – 3 line in our own and local galaxies.

Band 4 (125 – 163 GHz) covers a wavelength range where the atmosphere is very transparent even under mediocre conditions. It is a crucial band to measure redshifted CO and [CII] in critical redshift ranges. It also provides important opportunities for astrochemistry including deuterated molecules and measurements of the lowest frequency dust emission free from emission from ionized gas.

Development activities for ALMA frontend are very active in Japan. In 2002 July, the first engineering model (EM) for Band 8 cartridge with the single-mirror optics was cooled and measurements were made of the receiver noise temperature and gain stability. Pre-prototypes of Band 10 DSB receiver and Band 4 sideband-separating receiver are being developed as ALMA cartridges. These receivers are tested in the cartridge test cryostat, copies of which are being provided to the North American and European groups developing ALMA cartridges.

A photonic local oscillator for use at 100 GHz has been developed, and was verified to have the output power and low noise suitable for use in the ALMA system. Photomixers for higher frequencies are under development.

The submillimeter receiver developments are based on the experience of the 810 and 490 GHz receivers on the Mt. Fuji submillimeter telescope. It has been operated for four years under remote control and is producing an unprecedented amount of survey data in the [CI] 492 and 809 GHz lines. NAOJ has established mixer designs called Parallelly-Connected Twin Junction (PCTJ) for submillimeter bands and Non-homogeneous Distributed Junction (NDJ) for millimeter bands. For band 10 SIS junctions, tests are being made for two types of junctions with new materials, i.e. NbTiN and NbN. These technologies are applied to the EM cartridges.

It is planned to install the Band 8, Band 10, and Band 4 EM cartridges to the ASTE 10-m telescope in Pampa la Bola and test them in the real observing conditions.

The Second Generation Correlator

Build the Second Generation Correlator to be used for both the 64-element array and the ACA system. It has 8,000 – 64,000 spectral channels per baseline that can be used even at the maximum total bandwidth of 16 GHz. A flexible allocation of the frequency channels within the band is possible. A 3-bit sampling and processing is standard, which has a 8% gain in sensitivity (equivalent to adding five more 12-m antennas) relative to the 2-bit processing that is standard in the baseline correlator.

It will enhance the spectroscopic capability of ALMA by enabling observations with full bandwidth without sacrifice of number of spectral channels (i.e., spectral resolution) and sensitivity. This will make ALMA even more efficient and open a new field of science.

It can increase the observing speed of some highly ranked programs by a factor of two or more, especially in the areas of high-redshift galaxies and protoplanetary disks around young stars, which require long integration times. It also provides ALMA unique capabilities to probe deep into the centers of active galaxies and to make unbiased searches for absorption lines from the deep universe or for signals from pre-biotic molecules in planet forming regions.

NAOJ is one of the centers of expertise in design and development of multi-channel spectro-correlators for radio astronomy. Last year NAOJ has built a pre-prototype FX correlator for ALMA and tested it in the real observation with the Nobeyama Millimeter Array (NMA), which showed its spectacular power by detecting twenty different spectral lines from Orion-KL in one frequency setting. Japanese correlator team has coordinated the development effort with the European correlator team to reach a unified design for the ALMA Second Generation Correlator.

Infrastructure and operation

NAOJ will contribute to the infrastructure of the whole trilateral ALMA with a proper share. It includes the one needed for installation and operation of the proposed Japanese instrumentation.

NAOJ will contribute an appropriate share of the operational cost of ALMA.

4. Value Assignment, Representation in Committees, and Right to the Observing Time

The value of the Japanese contribution to the construction should be assigned based on a cost model to be agreed by the three partners. The appropriate representation in the ALMA Board and other committees and the right to the observing time and data need to be defined after negotiation based on the assigned value.

The table in the Appendix lists briefly the contributions to the ALMA project that NAOJ has already made or is making. NAOJ wishes to negotiate on values assigned to them when it becomes appropriate.

5. Steps Toward the Official Participation

Budget request in Japan

The Working Group on Astronomical Research under the MEXT (the Ministry of Education, Culture, Sports, Science and Technology) Science Council is currently assessing the proposal of Japanese participation described in the former section. The final report of the assessment is due in December 2002. NAOJ starts negotiations with the government in January 2003 for the FY2004 budget. NAOJ will submit the ALMA construction budget request to MEXT in June 2003. MEXT will submit the ALMA budget request to the Ministry of Finance (MoF) by the end of August 2003. The government budget draft will be released in the end of December 2003. An inclusion of the ALMA construction in it almost certifies its funding. It becomes fully approved when the Diet passes the FY2004 budget in March 2004.

Agreement

In parallel with the discussion at EACC on the Japanese participation proposal, a working group appointed by EACC needs to start drafting the agreement on construction and operation (we tentatively call it "agreement" here) immediately. It is important for the Japanese funding that NAOJ have the first draft of the agreement in hand when it negotiates with the government in early 2003. We hope that EACC can agree on the basic part of the agreement by October 2003 to ensure the Japanese funding and to leave enough time for final adjustments and ratification.

Milestones

2002 Sept.	EACC starts discussion on the Japanese proposal
	EACC charges ASAC and ALG with further consideration

2003 Jan.	NAOJ starts negotiations with MEXT, MoF, and Ministry of Foreign Affairs (MoFA)
2003 Mar./Apr	EACC agrees on the NAOJ budget request plan
	EACC discusses a draft trilateral agreement
2003 Jun.	NAOJ submits its budget request to MEXT
2003 Aug.	MEXT submits its budget request to MoF
2003 Sept./Oct.	MEXT states its intent
	EACC agrees on the basics of the trilateral agreement
2003 Dec.	Japanese government issues its FY2004 budget draft
2004 Mar.	Japanese Diet approves the FY2004 budget
2004 Apr.	Trilateral agreement signed (Japanese official participation)

6. Proposal for an Interim Framework in the Transition Phase

Considering the importance of the mutual communication and the coordination efforts to be made in the transition phase from the bilateral project to the formal start of the trilateral project, NAOJ proposes the following as the interim framework in the transition phase.

1) To continue the EACC function as a table for discussion on the Japanese participation and related matters,

2) To continue the Japanese involvement in the ASAC activities. In discussion on the Japanese participation plan, the Japanese members should have an official status equal to the members from Europe and North America,

3) To continue the ALG activities to keep the best liaison between the current Joint ALMA Office and the Japanese project management, and

4) To keep close communication in the DH/TL level between the bilateral project and the Japanese team.

When the prospect of the Japanese funding gets high enough, we need to establish the trilateral ALMA organization structure as early as possible to enable a smooth start of the trilateral project including the Japanese construction in FY2004.

Appendix

Past and Current Japanese Contribution to ALMA

1. Management activity at the ALMA-J office
2. Participation to committees and working groups
   (ASAC, imaging/calibration, science software requirement, etc.)
3. Site development and characterization
4. 12-m prototype antenna construction
5. 12-m prototype antenna evaluation
6. Frontend cartridge development
7. Development and provision of cartridge test cryostats
8. Photonic LO development
9. Sampler and correlator development for the Second Generation Correlator