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Report of the ALMA Liaison Group

March 21, 2000

1. Introduction

The Japanese LMSA project has been proposed with special emphasis on the scientific performance of the array at submillimeter wavelengths with a collecting area and spatial resolution comparable to fifty 10m antennas and 10km maximum baseline, respectively. A large FX correlator system with very high spectral capability has also been considered as a key device in the project.

Since the ALMA project has overlapping scientific interests with the LMSA project, participation of Japan as a major partner in ALMA is under consideration. To this effect, the ALMA Liaison Group (ALG) was established by the ALMA Coordinating Committee (ACC) and NAOJ. The members and the remit of the ALG are shown in the following :

<The ALG members >

Europe:	R. Kurz and S. Guilloteau
Japan:	M. Ishiguro (Chair) and R. Kawabe
U.S. :	R. Brown (Vice Chair) and P. Napier

<Remit of the ALG>

- To produce and evaluate options for Japanese contributions which would lead to the enhanced Atacama Large Millimeter/Submillimeter Array referred to in the Resolution signed 12 November 1999;
- To evaluate implementation paths for these options which are compatible with current planning constraints for ALMA;
- To select the most scientifically and technically advantageous option(s), and to propose mechanisms whereby the Japanese contribution can be integrated with ALMA to produce the single enhanced project;
- To present a report on the above to the ACC and NAOJ no later than 30 March 2000.

The ALG had three face-to-face meetings in Grenoble (Dec. 4, 1999), Tokyo (Feb.16, 2000), and Leiden (Mar.9, 2000). The implementation paths and their priorities are proposed for Japanese contributions to the ALMA project considering the best compatibility between the baseline ALMA project and the LMSA project.

2. Propositions for Japan participation to an enhanced ALMA project.

This section presents a number of possible contributions of Japan to an enhanced ALMA project. The enhancements resulting from the various propositions are quite varied : adding new capabilities (e.g. supra-THz capability), shortening the duration of the construction phase, increasing the sensitivity, simplifying the maintenance or reducing

global cost in some areas. Each proposed contribution is presented in 3 steps: a description, the expected improvement to ALMA, the method proposed to value the contribution.
In addition to the specific items mentioned below, which result in visible improvements, it is of course also expected that Japan shares the basic infrastructure and running costs of ALMA.

1) An addition of a number of 12-m antennas.

Description : Involvement of Japanese industry is essential for Japan participation in the project. Japanese industry could build up to $1/3^{rd}$ of the total number of 12-m antennas. These antennas would be built to the same or better specifications than the US-European antennas, with a possibly different design, but plug-in compatible in the same stations.

ALMA benefit : Antennas of similar performances would increase the ALMA sensitivity (or speed). Antennas of better performances would significantly increase the highest frequency capabilities of ALMA.

ALMA value : Unless antenna performance is significantly increased, it is proposed to evaluate this contribution on an equal value for each antenna, unrelated to its origin.

2) An addition of a number of smaller, high accuracy, antennas in a compact array.

Description : The enhanced ALMA project could include a compact array of small, but high surface accuracy, antennas. This array could take the form of, for example, a compact hexagon with 7 antennas of 6 to 8-m diameter. The outer antennas could be moveable on rails to allow fast reconfiguration in order to tailor the shape of the array to the source declination, to avoid shadowing effects. The antenna mount and receiver cabin could be identical to those of the 12-m antennas, allowing them to move on larger configurations also, and to have the highest compatibility for receiver interfaces. Expected antenna surface accuracy is of the order of 15 microns rms or better.

ALMA benefit : Such a compact array would enhance ALMA capabilities for short spacing measurements, specially at the highest frequencies where the 12-m antenna performances and the atmospheric properties make the problem most difficult. It would also allow operation of the 12-m antennas with an under-illumination pattern at the highest frequencies to select a better compromise of field-of-view and pointing performance versus sensitivity. The reconfigurable option would open the possibility for ALMA to explore the highest frequencies, perhaps even above 1 THz, with appropriate field of view and angular resolution.

ALMA value : Assuming the same complement of receivers as the 12-m antennas, we would give each small antenna the same value as a 12-m antenna.

3) A participation to the junction effort

Description : A new facility for SIS junction production is being developed in Mitaka. This facility could be used for ALMA junction production. Japan is also developing innovative technologies for junctions (e.g. the distributed junction scheme from Dr. Noguchi).

ALMA benefit : This contribution could alleviate a possible bottleneck in the ALMA project.

ALMA value : This contribution would be evaluated on the basis of the ALMA agreement for junction production value.

4) Fabrication of one/several receiver frequency channels

Description : Japan could provide e.g. the 490 GHz receivers for ALMA (or other bands), compatible with the ALMA receiver subsystem.

ALMA benefit : This could speed up the completion of the ALMA project, and avoid excessive retrofit actions to the receiver packages.

ALMA value : This contribution would be evaluated on the basis of the ALMA agreement for receiver band value.

5) Cryogenics

Description : Japan is probably the biggest supplier of cryocoolers, with proven reliability.

ALMA benefit : Basic contribution

ALMA value : Market prices

6) Photonics

Description : NTT is actively developing high frequency photodetectors, which may be suitable for the full photonic LO system for ALMA

ALMA benefit : Photonic LO system is simpler than the photonic reference approach.

ALMA value : Value based on estimated cost of the photonic reference plus multiplier solution and purely photonic approach, whichever is the most expensive. The gain in simplicity justifies extra cost (if any).

7) Correlator

Description : Japan is developing a wideband, 128,000-channel FX correlator. The goal is ultimately to cover the full 2 GHz bandwidth (perhaps even 4 GHz) with this number of channels. This removes the extra complexity of input filtering (analog or digital).

ALMA benefit : Line surveys could be carried out more effectively. Serendipitous discoveries are to be expected (e.g. molecular masers in stars). Multiple-line observation and continuum subtraction from narrow lines could be executed more precisely and effectively. Heavy molecules could be detected by pattern-matching integration of the line forests.

ALMA value : The value should be based on the observing time savings that such a correlator will provide for the astronomy projects requiring narrow lines observations. The induced computing cost resulting from the huge number of channels should be evaluated and accounted accordingly. The effective sensitivity should also be assessed.

8) More digital bandwidth

Description : Japan could provide enhanced transmission bandwidth from antenna to central building, and from central building to Operation Support Facility in San Pedro.

ALMA benefit : Current nominal bandwidth of standard fibers does not allow 3-bit samples to be transferred on a single fiber from the antenna. This would become possible. Ultra high speed link with OSF would allow relocation of the correlator and all its associated computing equipment to San Pedro.

ALMA value : Based on cost.

9) Other proposals mentionned

A few other options were discussed, including a large single-dish antenna, longer baselines, a super-computer for enhanced data mining capabilities, etc… These were felt impracticable, or to far from the scope of an enhanced ALMA project.

The options presented above were discussed at the ALG and among the ALMA community, and in particular presented at the Tokyo technical meeting.

3. Japanese contributions to ALMA and enhanced ALMA

Based on the above propositions, possible Japanese contributions are classified into two parts; 1) participation to the baseline ALMA project, and 2) enhancements to the baseline ALMA project. The ALG has investigated and evaluated their scientific benefit and technical importance. The "participation part" and "enhancement part" should be integrated to a single enhanced project following the agreed priority list.

- Participation in the baseline ALMA project

B.1 12m antenna elements

- Japanese group will accelerate the design and cost estimate of 12 m antennas to be compared with the US/Europe prototype antennas. Japanese antennas will be designed with a special emphasis on performance at submillimeter wavelengths. The antenna design should not necessarily be the same, but performance specifications and external interfaces (as specified in the Interface Control Documents) should be identical to the ALMA antennas.
- European, Japanese and US groups will exchange the necessary information to coordinate the design effort of the production antennas to make their antennas compatible.
- Japanese group will examine the Interface Control Documents and, if necessary, will propose modifications and/or additions.
- Japanese group will contribute one of the antenna transporters.

B.2 Fabrication of selected receiver frequency bands

- Japanese receiver group has already been participating in the ALMA phase 1 activities by providing a design for the band #8(385-500GHz) receiver frequency module. The effort could be extended to the band #10(787-950GHz). Japanese group will accelerate the design and cost estimate of the modules for those frequency bands. The ALG has tacit understanding that the groups responsible for each band will provide the receiver modules for all antennas.

B.3 SIS junction effort

- Japanese contribution to the junction fabrication is highly desirable to guarantee a stable supply of junctions in order to achieve a reliable operation of the telescope system. A plan of sharing the junction fabrication should be determined.

← all foundries have slightly different processes - requires mixer designers to change designs targeted for a different foundry & work closely with new foundry for ~1 year - is this practical?

B.4 Cryogenics effort

- Japanese group will contribute reliable components for the ALMA cryogenic system under the collaboration with Japanese industries. The reliability of the cryogenics will be evaluated with the actual experiences in the Japanese ASTE (Atacama Submilllimeter Telescope Experiment) project.

B.5 Photonic applications

- Japanese group is participating in ALMA phase I photonic development by developing a high frequency photodiode in collaboration with NTT. If successful, Japanese group will contribute to the photonic reference signal up to 390GHz.

There appears to be no clear advantage to a photonic reference signal above ~30 GHz, which can be done with COTS.

The "all photonic" option is also within the scope of the Japanese development and is recommended.

- If a photonic calibration system is proved to be very effective, Japanese group will contribute to the implementation of the system in ALMA.

B.6 High speed sampler

- Japanese group is participating in the phase I of ALMA by developing a high speed sampler in collaboration with OKI. If successful, Japanese group will contribute to the implementation of the system in ALMA.

we need the whole module, not just the A/D

B.7 Infrastructure

- Japan will contribute a proportional share to general infrastructure (including antenna pads, electric power transmission, signal transmission, access road, buildings, ...).

- Enhancements to the baseline ALMA project

E.1 Increase the total number of 12m antennas

- The total number of antennas in the enhanced ALMA could be increased beyond the 64 in the ALMA baseline. The number should be determined based on the scientific rationale as well as the impact to the total cost.
- The same conditions as in B.1 could be also applied here.
- The ALG will recommend the optimum number of antennas to be shared between Japan and US/European groups.

← especially to baseline correlator - could go to say 80, but need to know

E.2 Ultracompact array with smaller antennas

- European, Japanese and US groups recognize the importance of the small array of smaller antennas to fill the gap in short spacings and will jointly study the design and cost estimate of the ultracompact array.
- Considering the higher cost for a small number of antennas, the ALG recommends that each smaller antenna be given the same value as a 12m antenna.

E.3 More digital bandwidth

- Technology for tera-bit data links already exists in Japan and there is a possibility of Japanese contribution in this area. Japanese group will estimate the cost of an enhanced link system if US/Europe group consider this a valuable contribution.

E.4 "Future" correlator

- The ALG recommends that Europe and Japanese groups collaborate on the development of the "future" correlator system.
- In order to define the joint development program, the basic correlator architecture (i.e. FX vs XF) should be agreed.

Leaving NRAO out entirely?

E.5 Large computer system for data archiving and mining

- There is a possibility of Japanese contribution in introducing a large computer system.