Amendment #2 to the

AGREEMENT

CONCERNING THE CONSTRUCTION OF THE ENHANCED

ATACAMA LARGE MILLIMETER/SUBMILLIMETER ARRAY

(ALMA)

BETWEEN

THE EUROPEAN ORGANISATION for ASTRONOMICAL RESEARCH in the SOUTHERN HEMISPHERE and THE NATIONAL SCIENCE FOUNDATION of THE UNITED STATES

and

THE NATIONAL INSTITUTES OF NATURAL SCIENCES of JAPAN

WHEREAS

NINS and Academia Sinica in Taiwan (hereafter AS) have completed an Agreement for collaboration concerning the construction of the Enhanced ALMA, signed in Tokyo by NINS on 5 September 2005, and by AS on 8 September 2005.

ESO and NSF jointly agree with NINS that the Agreement concerning the Construction of the Enhanced Atacama Large Millimeter/submillimeter Array (ALMA), plus Amendment #1, shall be further amended in accordance with Article 6 of that Agreement as follows:

ARTICLE 1: DEFINITIONS

3. "**Bilateral Agreement**" means the "Agreement Concerning the Joint Construction and Operation of the Atacama Large Millimeter Array (ALMA)" between NSF and ESO, signed by NSF on 7 February 2003, and by ESO on 25 February 2003, and all subsequent Amendments.

4. "**ALMA**" means, for the purposes of this Agreement, the Atacama Large Millimeter/submillimeter Array being constructed by NSF and ESO under the Bilateral Agreement plus the additional contributions made by NINS as set out in this Agreement.

5. "**Enhanced ALMA**" is replaced throughout this Agreement by the term "ALMA" as defined in this Agreement

7. "**Observing Time**" means the time scheduled for the observing of astronomical objects for scientific purposes, excluding the time required for Engineering and Commissioning.

ARTICLE 3: SCOPE

1. This Amended Agreement covers Construction and Operations and provides the framework whereby NINS contributes to ALMA. Through this Agreement NINS participates with ESO and NSF in the construction of ALMA.

2. Article 3 2. is deleted.

ARTICLE 4: NINS PARTICIPATION IN ALMA

Chile

3. Article 4 3. is deleted.

8. Local staff required in Chile for ALMA shall be employed by the NSF Executive, and will be made available to NINS under separate agreements with the NSF Executive.

Contributions and other costs

10. The contributions made by NINS to ALMA shall be through deliverables Valued according to the ALMA costing model and attached to this Agreement on signature in September 2004. Contributions shall be deemed delivered when accepted by the ALMA Board upon the recommendation of the ALMA Director. Values may be adjusted by the ALMA Board according to the delivery schedule achieved. A description of the contributions to be made by NINS is attached to this Amendment at Annex A and B, and the schedule of delivery and Values at Annex C and D.

12. Notwithstanding the Value assigned to the NINS contributions and set out in Annex D, NINS shall make contributions to the infrastructure of ALMA which shall reflect the requirements of NAOJ and the actual cost to ESO and NSF of such infrastructure, and which shall be paid on a schedule to be agreed by the ALMA Board within 10 months of the signature of this Amendment.

13. Article 4 13. is deleted.

14. ESO and the NSF Executive may provide goods and services to NINS as part of ALMA. Such goods and services shall be the subject of separate agreements, contracts, or arrangements between NAOJ and the Executives, as appropriate, which shall be subject to the approval of the ALMA Director and acceptance by the ALMA Board. These goods and services have been included in the Value of the contribution made by NINS.

Operations

22. NINS shall contribute to Operations and Early Operations according to an Operations Plan produced and updated by the JAO and approved by the Board. The NINS share of the cost of Operations and Early Operations, as approved by the Board, shall be in exact proportion to the share of Observing Time and Early Observing Time, after subtraction of the 10% awarded to Chilean astronomy, awarded to NINS. The total cost of Operations shall be reviewed at regular intervals agreed by the Board, and shall be approved by the Board.

ALMA Board and other bodies

23. NINS may appoint up to three members to the ALMA Board immediately the Board has agreed the schedule of payments referred to in Article 4 12. The members appointed by NINS shall be entitled to vote on all matters except financial matters related to the bilateral construction project.

ARTICLE 5: OBSERVING TIME

1. NINS shall be awarded Observing Time and Early Observing Time proportional to the Value of the deliverables accepted by the ALMA Board as contributions to ALMA, amounting to a maximum of 25% of the Observing Time and Early Observing Time available after subtraction of the 10% awarded to Chilean astronomy when all contributions have been

accepted, except that this share shall be at most 22.5% until such time as the ALMA Board has accepted Band 10 as a contribution to ALMA.

2. The ALMA Board may adjust the Value of contributions, and hence the share of Observing Time and Early Observing Time, should the schedule of delivery deviate from the milestones set out in Annex C or should the contributions to infrastructure identified in Article 4 12. fail to materialize on schedule. Should these deviations be caused by delays in the delivery of goods and services provided by AUI or ESO, the Board shall take such delays into account in any adjustments.

3. The Observing Time available during Early Operations and Operations shall be allocated by the ALMA Director in accordance with policies and procedures determined by the ALMA Board as specified in Article 15.5 of the Bilateral Agreement.

For the National Science Foundation of the United States:

Arden L. Bement Jr.
Director
NSF

12 July 2006

Date

Washington D.C.

Place

For the European Organisation for Astronomical Research in the Southern Hemisphere:

Catherine Cesarsky
Director General
ESO

29 June 2006

Date

Garching

Place

For the National Institutes of Natural Sciences of Japan:

Yoshiro Shimura
President
NINS

4 July, 2006

Date

Tokyo

Place

ANNEX A: Project Description

Terminology

12-m Array; the array of 64 (initially 50) 12-m antennas provided by ESO and NSF.

ACA; Atacama Compact Array composed twelve 7-m antennas and four 12-m antennas provided by NINS. The term, ACA, is used in general to express the whole system.

- **7-m Array**; array of twelve 7-m antennas in ACA mainly operated as an interferometer.

- **TP (Total Power) Array**; four 12-m antennas in ACA mainly operated as single dish telescopes

- **ACA full array**; array composed of 7-m + TP Arrays, operated as an interferometer for mainly taking calibration data.

Coordinated observations; Observations of common observing programs with both the 12-m Array and ACA that are executed separately. This is a major observing mode for ACA in which no cross correlations between the 12-m Array and the ACA are obtained.

Technical overview of ALMA enhancement

The Japanese enhancement to ALMA is composed of two parts. One is the ACA for achieving complete uv-sampling and enhancing imaging fidelity especially for extended sources. The ACA is composed of twelve 7-m antennas (7-m Array) for taking short baseline data and four 12-m antennas (TP Array) for taking total power data. Another is three new receiver bands, Band-4, 8, and 10, for mostly covering available atmospheric windows shorter than 3 mm and enhancing ALMA observing capability in millimeter and submillimeter wavelengths.

1) ACA System

The Atacama Compact Array (ACA) will be built by Japan as an enhancement of the ALMA 12-m diameter antennas (12-m Array) located on the Chajnantor Altiplano in the Atacama Desert of northern Chile with a partnership of North America, Europe and Japan/Taiwan. It is a millimeter and submillimeter wave imaging system consisting of four 12 meter-diameter antennas for total power observation (TP Array) and twelve 7 meter-diameter antennas for interferometer (7-m Array) for supplementing short-spacing data to the 12-m Array. The ACA system is designed for use as a part of the entire ALMA system.

A tabular summary of the instrument's basic characteristics is shown in Table 1.

Additional details are as follows:

Site Location: The ACA is sited as close to the compact configuration of the 12-m Array as possible to exploit the correlation with the 12-m Array.

Antennas and Antenna Configurations: The TP Array antennas are 12 meter-diameter Cassegrain-fed paraboloids, with an aggregate rms surface error < 25 μm. The 7-m Array antennas are 7 meter-diameter Cassegrain-fed paraboloids, with an aggregate rms surface error < 20 μm. Each antenna is fully steerable and designed for rapid position-switching (up to 1.5 degrees in 1.5 seconds); more than 85% of the celestial sphere is visible from the Chajnantor site.

The antennas are all movable using a specially designed antenna transporter, provided by ESO and NSF, among 22 prepared ACA antenna stations. Each station has a concrete foundation to support the antenna and provision for electrical power and data communications. The TP Array is capable of taking single-dish images that contain information of zero-meter baseline. 7-m Array antenna configuration is arranged to make up for a *uv* gap from 6 to 15 m between 12-m Array and TP Array.

Table 1: ACA Technical Summary

ACA Array	
Number of array	2 (TP Array, 7-m Array)
Number of antennas	4 (TP Array) + 12 (7-m Array)
Total Collecting Area	914 m^2
Total Collecting Length	132 m
Angular Resolution	5" λ(mm) / baseline (km)
ACA Array Configurations	*(dimension of filled area)*
Area	< 80 m × 80 m
Configuration type	2 (standard/ NS-elongated)
Total Number of antenna Stations	22
ACA Antenna	*{TP Array / 7-m Array}*
Surface Accuracy of 12-m antenna	25μm RMS
Surface Accuracy of 7-m antenna	20μm RMS

Pointing	0.6" RSS in 9 m/s wind
Path Length Error	< 15 μm during sidereal track
Fast Switch	1.5 degrees in 1.5 seconds
Transportable	

Front Ends {All frequency bands - dual polarization }

84 – 116 GHz	
125 – 163 GHz	
211 – 275 GHz	
275 – 370 GHz	
385 – 500 GHz	
602 – 720 GHz	
787 – 950 GHz	
Water Vapor Radiometer	183 GHz (TP Array only)

Intermediate Frequency (IF)

Bandwidth	8 GHz, each polarization
IF Transmission	Digital

ACA Correlator

Correlated baselines	120 (16 x 15 / 2)
Bandwidth	16 GHz per antenna
Spectral Channels	8192 per IF

Data Rate

Data Transmission from Antennas	120 Gb/s per antenna, continuous
Signal Processing at the Correlator	1.6 x 10^{16} multiply/add per second

Front End Electronics: Each antenna will be equipped with seven receiver cartridges – one for each frequency band – housed in a common 4 K cryostat. All detectors are coherent, and rely upon a local oscillator signal phase-locked to an array frequency reference standard. Each receiver cartridge includes two receivers, operating in orthogonal senses of linear polarization. Off-axis from the Cassegrain focus of each antenna, a radiometer tuned to the 183 GHz atmospheric water vapor line will measure the column density of water above the antenna and enable the distorting effects of the water to be removed. The water vapor radiometer is implemented in TP Array only.

Back End Electronics: Signals from each front end receiver will be converted to a common intermediate frequency (IF), amplified, and digitized at the antenna by the backend electronics. In order to process the 8 GHz bandwidth of the IF, the backend electronics will subdivide the IF into four 2 GHz sub-bands for transmission to the correlator.

ACA Correlator: The correlator combines the digitized IF signals from each pair of antennas in the array, and creates astronomical images by Fourier transforming the complex phase and amplitude of the correlated signals. There are up to 120 possible pairs of antennas in the ACA.

Compatibilities with the 12-m Array

Because the site, cabling, computing, system integration, science commissioning and operation are merged with 12-m Array, the ACA design will be in conformance with the ALMA baseline system design except for some subsystems which have to be specific for the ACA scientific requirements. The technical requirements for RF Bands, IF and Digital Transmission Subsystem and LO reference Subsystem are the exactly same as those of 12-m Array.

2) Enhancement of the 12-m Array System

NAOJ will equip the 12-m array with additional dual polarization receivers covering 3 atmospheric windows: 125 - 163 GHz, 385 - 500 GHz, and 787 - 950 GHz, referred to as Bands 4, 8, and 10. The scientific importance of the new frequency bands is described in Annex B.

ANNEX B: Science Requirements

B-1) ACA

ALMA will image cold molecular gas and dust in the universe, from which stars, planets, and galaxies are formed. ALMA also images atomic gas where molecular clouds are thought to be formed. The emission from such gases and dust are thermal except for special cases (e.g., maser emission by molecules as non-thermal emission). Such objects observed by ALMA are usually spatially extended in nature and extended over the primary beam of the ALMA 12-m antenna in most cases. Such extended emission should be sampled for high fidelity imaging and for quantitative study such as gas mass estimate or the estimation of column density profile using thermal emission. Without the ACA, the images will miss key information, and this leads to an inaccurate interpretation of the data, as demonstrated by the scientific analyses performed so far. In the submillimeter wavelength, the importance of ACA increases because the field of view (primary beam) of the 12-m Array decreases inversely proportional to the observing frequency and the observing targets are getting larger than the primary beam width.

In summary, the scientific requirement for the ACA Antennas is defined to provide short baseline data and total power data with high precision in order to complement the 12-m Array data and to enhance the image fidelity particularly for extended astronomical sources. The short baseline data are provided with the 7-m Array with a very compact configuration, which is surrounded by the four antennas of the TP Array.

B-2) New Frequency Bands

The major science impacts of the three new receiver bands are:

1) to expand the coverage of main CO lines and [CII] line (principal cooling line of neutral atomic gas) with redshift,

2) to cover dust emission over the wider range of observing frequencies to determine the dust properties and photometric redshift for high-z forming galaxies,

3) to enhance the ability of ALMA to probe interstellar gas in a wide range of physical conditions,

4) to enhance ability for spectral line survey & astrochemistry, and

5) to achieve ultimate high spatial resolution.

A supplementary description of impacts by each receiver band is summarized in the following.

a) Band-4; 125-163 GHz

Band-4 covers a frequency range of 125-163 GHz which is one of the very transparent atmospheric windows in millimeter and submillimeter wavelengths. The band is very rich in molecular lines, some of which are masers, and one of key bands to probe astrochemistry in star forming regions, circumstellar envelopes of AGB stars, and protoplanetary disks.

Band-4 is also a critical band to measure CO and CII (also CI) in critical redshifted ranges and extend observable redshift ranges in the early universe. There are two important redshift ranges probed by Band-4. One is the ultimately high redshift range, z=10-14, which can be explored using the [CII] line. Another is a unique range, z=0.4-0.8 with CO(2-1), in which strong evolution of star formation activities occurs. This range cannot be accessed with band-3 and band-6. This band is also important to measure so-called photometric redshift, because at z = 10 band-6 and band-7 trace only the peak of dust spectrum.

b) Band-8; 385-500 GHz

Main driver of this band is a ground-state fine-structure line of neutral carbon [CI] (492 GHz), which can trace a transition region (thin layer of molecular gas) between atomic gas and molecular cloud. This line and the excited [CI] line at 809 GHz are the only major fine structure lines in the ALMA frequency range, and play important roles for the understanding of molecular cloud formation and destruction.

With the [CII] line, Band-8 can also cover a redshift range, z= 2.7 to 3.8, where the universe is very active in star formation.

c) Band-10; 787-950 GHz

Band-10 is the highest observing frequency of the ALMA, and challenging in its implementation and observations but very rich in science. Band-10 should cover the atmospheric window around 350 μm and achieve high sensitivity in the same level as that in the other sub-millimeter receiver band.

In Band-10 observations, ALMA can achieve the highest spatial resolution (e.g., 0.01 arcsec with the ALMA largest configuration) as far as S/N ratio is sufficient enough. This helps one of ALMA level-1 science cases; that is to resolve and explore the earth-like planet forming regions in nearby protostellar disks.

In terms of highest observing frequency, Band-10 is also very useful for determination of spectral energy distributions (SED) in the wide frequency range of millimeter to submillimeter wavelengths. Especially, Band-10 is a key frequency to estimate rough redshift of distant forming galaxies with a photometric redshift analysis of dust emission.

In terms of spectral line observations, one of two neutral carbon lines [CI] at submillimeter wavelengths is observable with Band-10 ([CI] at 809 GHz). This line is crucial for the understanding of molecular cloud formation and PDR. Redshifted [CII] (ionized carbon line) is also observable for high-z galaxies at redshift of 2. This allows the acquisition of information on carbon in molecular, neutral and ionized gases. In Band-10, there are various molecular spectral lines which are useful for diagnosis of warm and dense molecular gas (e.g., CO, ...) and also a unique maser lines of molecules such as HCN.

ANNEX C: Project Time Schedule – ACA Major Milestones

2004 September	ESO/NINS/NSF Agreement on Enhanced ALMA
2006 June	Amendment to the ESO-NSF-NINS Agreement
2007 Q1	1st Band 4 and Band 8 cartridges delivered at the Front End Integration Center (FEIC)
2007 Q4	1st ACA 12-m antenna delivered at OSF
2007 Q4	Start AIV activity for ACA
2007 Q4	Band 10 Preliminary Design Review
2008 Q2	ACA correlator delivered at AOS
2008 Q2	Start commissioning of 1st ACA 12-m antenna (total power mode)
2008 Q4	4th ACA 12-m antenna delivered at OSF
2008 Q4	1st Band 10 cartridge delivered at FEIC
2009 Q3	1st ACA 7-m antenna delivered at OSF
2009 Q3	Four ACA 12-m antennas commissioned and available for science verification/demonstration science
2010 Q3	12th ACA 7-m antenna delivered at OSF
2011 Q1	ACA with 16 antennas commissioned
2012 Q1	Delivery of Band 4 and Band 8 cartridges complete
2012 Q1	Start full science operation including ACA
2013 Q4	Delivery of Band 10 cartridges complete

This schedule is preliminary and shall be revised and submitted to the Board for approval no later than 7 December 2006.

ANNEX D: List of Deliverables to be provided by NINS and their Maximum Values

TASK	MAXIMUM VALUE (kUSD of year 2000)
Contribution to Power Plant	**11,200**
Administration of ALMA-J Project Office	**4,030**
ACA	
ACA infrastructure	16,000
ACA Antenna	
Management for Antenna Tasks	3,299
Four 12m Antennas	12,790
Twelve 7m Antennas	24,960
ACA Front End Costs	
Front End Subsystem Management & Engineering (8yr) (Excluding Band 10 related)	2,230
Cartridge Test Cryostats already delivered to NA/EU	696
Integration Task for ACA Front End (excluding Band 10 related)	3,012
Other Front End Items (WVR)	489
ACA Front End	18,401
ACA Correlator	
ACA correlator	2,821
ACA Computing	

Software Costs associated with ACA	7,573
Hardware Costs associated with ACA	1,175
ACA backend	14,965
ACA, Total	**108,411**
New Frequency Bands	
Integration Task for Bands 4,8 (Band 10 Integration inc. below)	2,753
Band 4	
Cartridges, LO materials	13,279
Band 8	
Cartridges, LO materials	15,798
Band 10	
Cartridges, LO materials (includes D&D, management, integration) , not to exceed	20,816
New Frequency Bands Total	**52,646**
System Engineering & Integration	**2,014**
Science (5yr)	**2,000**
Total	**180,301**